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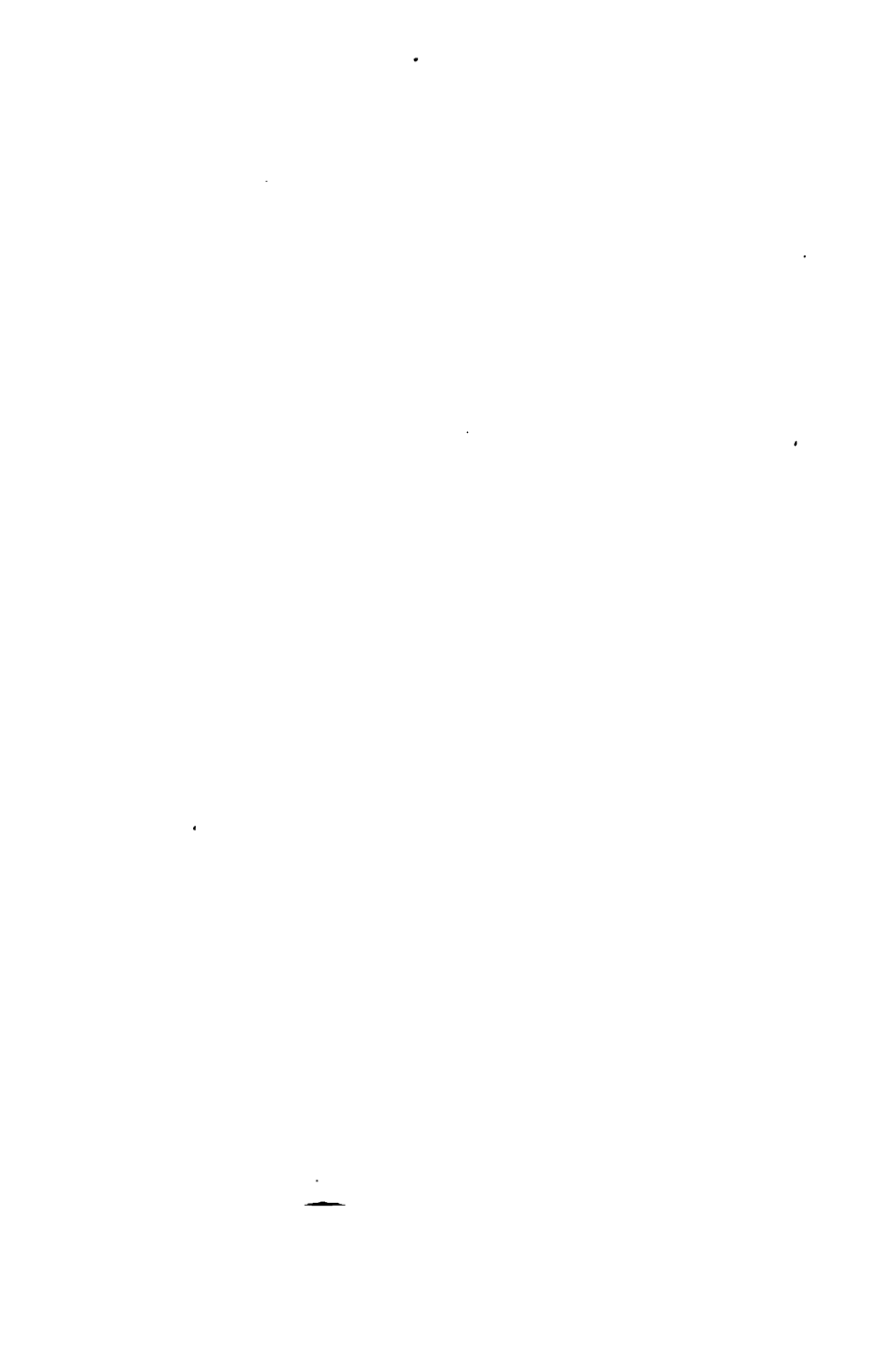
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FIRST LESSONS
IN
MODERN GEOLOGY

HENRY FROWDE, M.A.

PUBLISHER TO THE UNIVERSITY OF OXFORD



LONDON, EDINBURGH, AND NEW YORK

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FIRST LESSONS

IN

MODERN GEOLOGY

BY THE LATE

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EDITOR'S PREFACE

THE manuscript of the accompanying book was left by the late Professor Green in a somewhat unfinished condition, and the Editor was asked by Mrs. Green to prepare it for the press. The author had made a general scheme of the various 'Lessons,' and afterwards appears to have written the text of each separate one independently and at different times, and had not been able to go over them subsequently to co-ordinate them, when he was unhappily removed from among us. It was necessary, therefore, to somewhat rearrange the matter, remove repetitions, and supply connecting links. Occasionally an extra detail has been added, but the only addition of bulk is the last Lesson—on Fossils.

Of the illustrations, Figures 23, 24, 25, 26, 31, 32, 34, 35, 39, 40, are from drawings accompanying the manuscript. These, and Figures 3, 6, 8, 15, 16, 20, 36, 37, 38, are new; the remaining twenty-three out of forty-two are copied from previously-published figures.

The title suggested by Professor Green had some

reference to schools, but as such reference might possibly repel some who would find the work interesting the Editor has suggested a more general title, which need not prevent it being used in schools. The book is practically a Primer, but the author was never fond of using a Latin word when an English one would express his meaning, and the title adopted seems better to foreshadow the character of the book.

J. F. BLAKE.

July, 1898.

CONTENTS

LESSON I.

	PAGE
What Geology can teach us	I

LESSON II.

What Sandstone is made of	9
-------------------------------------	---

LESSON III.

What Quartz is made of. The meaning of Chemical Elements and Compounds. Definition of Minerals. Difference between Minerals and Rocks. How to know Minerals. What Clay is made of. What colours Sandstones and Clays	17
--	----

LESSON IV.

How Sandstones and Clays are produced. What they were made from. The Weathering of Rocks. Denuding Agents. Bedding and how it was caused. Different kinds of Sandstones and Clays, and some of the structures found in them	34
---	----

LESSON V.

What Limestone is made of. Calcite. Flint and Chert . . .	51
---	----

LESSON VI.

How Limestones were formed	58
--------------------------------------	----

LESSON VII.

On the Distribution of the Material brought down by Denudation. How we can learn what was Land and Sea long years ago.	72
--	----

LESSON VIII.		PAGE
About Rock-salt, Dolomite, and Gypsum, and how they were probably formed		81
LESSON IX.		
About Coal and how it was made		91
LESSON X.		
About Glaciers and Ice-sheets, and how we learn that there were once Glaciers and Ice-sheets in countries where there is now nothing of the kind		103
LESSON XI.		
About Crystals		114
LESSON XII.		
About Crystalline, Glassy, and Fragmentary Rocks		125
LESSON XIII.		
Reasons for believing that some Crystalline Rocks and their associates are the products of old Volcanoes		137
LESSON XIV.		
Of the Rocks called Plutonic		146
LESSON XV.		
How Rocks have been bent into folds, puckered and broken across, and moved from the places in which they were formed. What is meant by Unconformity		155
LESSON XVI.		
Of some ways in which Rocks have been altered in structure since they were formed		173
LESSON XVII.		
How the Surface of a Country is affected by its Geology		190
LESSON XVIII.		
About Fossils. How they are preserved, and what they teach us.		200
INDEX		209

FIRST LESSONS IN MODERN GEOLOGY

LESSON I

WHAT GEOLOGY CAN TEACH US

‘WHAT is the meaning of the word Geology?’ and ‘What is it that Geology will teach me?’ ought to be the first questions asked by any one who is beginning a study of that science, and the first thing for a teacher to do is to answer them.

The reply to the first is that Geology is the science that tries to find out all that can be known about the earth on which we dwell; about the earth itself as distinguished from the plants and animals that live upon it; about the earth in its natural state, setting aside anything that has been placed upon it, or any changes that have been made upon its surface by the agency of man.

But this answer will only prompt the further question, ‘What is there to be learnt about the earth which we do not know already from Geography?’ We know its shape and size; we know how much of it is dry land and how much is covered by water; we know, too, a great deal about the mountains, valleys, and

2 *First Lessons in Modern Geology*

plains of the land, and the depth and outline of the basins in which the waters lie. All this, and much besides, Geography has taught us, and what more can Geology do?

A very little thinking will show that there are a great many points connected with the earth, besides those just mentioned, on which it would be interesting to have information; and a simple illustration will, perhaps, make it clear what some of these points are. Consider the house in which any one of us is living. We know very likely its general shape, and its height and length and breadth. We know also how many rooms there are, how large each room is, and the use to which it is put. Many people might be content to know no more than this, but this is clearly very far from being a complete account of the house, and we can easily imagine that a person of an inquiring turn of mind might ask many additional questions, amongst which the following would be the most important.

What is the house made of? How much of it is stone, brick, iron, wood, plaster, or other materials? Just in the same way the first question asked by Geology, and which Geology is to a certain extent able to answer, is: 'What is the earth made of?'

Then again, how was the house built? Where did its materials come from? How were they brought? How were they fashioned into their present shape? and how were they placed in the position in which we now see them? Similar questions suggest themselves about the earth. Has it been built up gradually like a house? Where did its materials come from? and how were they brought and placed where now we find them? Now Geology answers that the earth has been so built up, and it can in some measure tell us whence and by what

means its materials were brought together, and how they came to be arranged in their present order.

The building of the house too may not have been one continuous process, but it was perhaps raised at one time by an additional story; a bay window was thrown out some time afterwards; and later on a wing was added. Parts also may have been pulled down, and their materials used in building up part of the house afresh. Have any changes, it may be asked, corresponding to such as these, ever happened to the earth? Geology answers 'Yes.' The framework of the earth's surface has been changed over and over again, parts of it have been pulled to pieces, and have either been worked up into new shapes on the spot or have been carried away and used elsewhere in another part of the building.

Then again, the house has not always been occupied by its present inmates; a succession of families has lived in it; it has been vacated sometimes on account of the death of its inhabitants, sometimes on account of their removal—and in either case new tenants have taken possession of it. Geology teaches us that changes in the earth's inhabitants have taken place in bygone times, the animals and plants which tenanted the surface have changed many times over; sometimes they died off one by one, and were gradually replaced by forms altogether new; sometimes they shifted their quarters from one part to another, and were replaced by creatures which had hitherto lived elsewhere.

And the example of the house may illustrate the way in which we learn about these changes. For in going into a house which the tenants have just vacated, we may find that they have left behind them tell-tale relics, showing what kind of people they were. If in one room we find a heap of broken toys, we know there must

4 *First Lessons in Modern Geology*

have been a family of small children ; if in another we find amongst the waste paper some printer's proof-sheets, we infer that amongst the tenants there was a writer of books ; and similarly from such things as torn canvas, cigar ends, or hair-pins. Just in the same way the animals and plants that dwelt on the earth in former days have, in many cases, left behind them parts of the framework of their bodies, or other relics, from which we may learn much about their character, and how they resembled or differed from the creatures of to-day.

This will be quite enough to show that Geology can tell us a great many things, well worth knowing, and the next step will be to explain how these things are found out.

Starting with the first question, 'What is the earth made of?' we naturally begin at the surface. But in many places the surface is obviously altered artificially. In towns there is quite an accumulation of ancient rubbish ; in the cultivated country we find the ground covered over by grass, or ploughed and sown, and underneath we find nothing but loose brown soil, so that in many places it seems rather difficult to get at what lies below. But even in such places, if we hunt about over the country, we shall be almost sure, somewhere, to light upon a brook which cuts much deeper into the ground than we can dig ; in default of which we must seek some brickyard, stone-quarry, or railway cutting, or if we are near the sea the cliff will often give us a sight of the material which is a long way below the surface of the land in the neighbourhood. Any hole or cutting of this kind which enables us to see what lies below the surface-soil is called a *section*—a *natural section* if it is made by brook, river, sea, or any natural agent ; an *artificial section* if made by the hand of man.

Now just as there are many sorts of soil, so there are many sorts of things below the soil. Let us start in an upland district, where we shall find all the sections begin with very much the same story. At the top there is nearly always soil formed very largely of the decay of the plants that have formerly grown on the surface. This soil is a coarse kind of powder, all the grains of which are about of a size. A little way down the soil becomes lumpy, the same coarse powder as we found at the top being here mixed with larger and harder pieces. These pieces become bigger and more numerous the deeper we go, till after a time what we dig up consists of scarcely anything else. Going still further down, the lumps begin to stick together, and at last we reach solid stone of some kind. We then find that the lumps above are simply pieces which have been broken off this stone.

Next let us go to an open valley where the soil is clayey. Here the upper part would be comparatively light, for it would be broken up by the weather and mixed with the remains of vegetable growth, but the soil would grow stiffer and stiffer the lower we went, till at last we should come to unaltered and unmixed clay, which, though it might not be very hard, was still solid.

If the soil again were sandy we should find it less mixed with vegetable matter the further we went down, till the pure clean sand was reached.

The stone, clay, or sand, or whatever it is that we find underneath the soil, is called the *subsoil*, and the different kinds of soil are mostly due to the different kinds of subsoil out of which they are for the most part made.

All the different kinds of substance that make up the subsoil of the earth are called Rocks by geologists: they may be very hard, like granite; easier to break than granite, but still tough enough to stand a good blow,

6 *First Lessons in Modern Geology*

like limestone; soft enough to be cut by a knife, like clay; or friable so that they may be crumbled between the fingers, like sand; but in the language of Geology they are all rocks.

To know, then, what the earth is made of we must study all the different kinds of rock which we can obtain from many localities, and search out all the best and deepest sections where these are exposed. But the very finest of these sections will not show the materials of the earth beyond the depth of a few hundred feet, at least in England, or a few thousand feet in the deep gorges of America. We may, however, learn what is the composition for some way further down in mines and borings, but as yet no new kinds of rock have thus been discovered; but the very same rocks that at one place form the subsoil, at another will be found at the greatest depth to which a mine or boring or a river gorge has ever reached.

But how far does this carry us? The depth of the deepest mine is short of a mile, while the distance from the surface to the centre of the earth is four thousand miles. We may, however, feel our way with considerable certainty somewhat further in than this. We have no reason to believe that there is any sudden change just below the depth reached by our deepest sections, and what we learn of the rocks in the first mile almost shows us, as we shall subsequently learn, what there *must* be for the next few miles below. The part of the earth, then, which we can examine with our hands and eyes, or about whose composition we can make a very fair guess, is really a very small portion indeed of the whole earth, only a thin cuticle, rind, or shell, which, because it is so thin, is called *the crust of the earth*. If we take a pair of ordinary compasses and draw as large

a circle as we can, say 8-in. radius ; if the thickness of the line be only one-fiftieth of an inch, it will show about the same proportion as this crust.

But thin as it is in proportion to the whole globe, we shall find work enough to occupy us for some time if we would learn all that is known about the rocks which it contains. What lies beneath the crust is quite another matter, and must be found out, if at all, in quite a different way. Though we can never get down to actually see what is there, nor infer its nature from what we see above it, it does not follow that we must be quite in the dark on the subject. For instance, we are quite sure that somewhere inside the earth there must be something very different from the rocks which make up the crust. This we can safely say, for it has been found possible to weigh the earth as a whole, and the result is that the actual earth is about two and a half times as heavy as it would be if it were made up of the same kind of material as forms its crust. Thus there must be a quantity of heavy stuff within the crust, and there are reasons for thinking that much of this heavy stuff must be iron.

But questions about the inside of the earth we must put by till we have made some advance in Geology, and give our whole attention to the crust. We will take one by one the commoner kinds of rock found in the earth, and we will try and make out what each is made of. Next we will ask whether the rock has been in the place we took it from ever since the earth came into being, or whether there are any grounds for thinking that the rock is not as old as the earth, but has been made by nature, somewhat in the same way as we know that the houses which stand on the earth's surface are not as old as the earth itself, but have been built up by men. In every case we shall find proof that the rock has been made by

8 *First Lessons in Modern Geology*

nature, and we shall then have to make out the steps of the process, where the materials came from, how they were brought, how they were worked up into their present form, and how they were placed as we now find them.

When all these questions have been answered, there will yet remain much to be done. Different rocks were made by nature at different times, and we shall find that it is possible to fix the order in which they were made; we shall be able to parcel out the rocks of the crust into groups and say—this is the oldest group we know, this followed, this came next, and so on. We shall work out a history of the formation of the earth's crust, very like the history of a nation; but instead of saying that anything happened during the reign of this or that king, we shall say during the period when this or that group of rocks was made, or during the period when this or that group of animals flourished. For just as in the history of a country we find that different races of men inhabited the land at different times, so we shall find that the earth has not always been tenanted by the same kinds of animals and plants, but that one set after another has arisen on its surface, dwelt there for a while, and then passed utterly away.

The rocks we are about to deal with first are the common ones which bear such ordinary names as sandstone, clay, and limestone; it is only later, for less common rocks, that new and more technical names are necessary.

LESSON II

WHAT SANDSTONE IS MADE OF

WE will in this lesson try our hands on a bit of sandstone, and see how far we can find out what it is made of.

There are many kinds of sandstone, and though we may employ the same methods with all of them, we had better choose one in which the results of our search will most easily be obtained. Do not then select a piece of very hard, closely grained, clean-looking rock, but choose rather a coarse, crumbly, dirty-looking sandstone of yellowish or brownish, not of a red or grey colour.

In many parts of the country there are plenty of quarries where specimens of such a sandstone may be picked up; if such are not handy a suitable piece can often be obtained from the rejected fragments in a stone-mason's yard. Take a piece of such sandstone, about as big as the end of your finger, and crush it with a hammer. Put the powder into a small mortar with a little water, and stir it about well with the pestle. Do not pound it, but work it round, and rub up water and powder together. Now throw the whole into a beaker of clean water. Allow the mixture to stand for a minute or two, and let the heavier part sink down, and then pour off the muddy water gently and cautiously into a shallow beaker. Rinse back into the mortar all that is left in the first beaker and again work it round with water, then empty the

whole into the beaker of muddy water ; after allowing a short time for settling, pour off the muddy water into the first beaker and return the sediment to the mortar to be again washed up with water. Repeat this process about half a dozen times, and set aside the beaker of muddy water in a place where it can stand for twenty-four hours, without being disturbed, marking it No. 1.

We have now managed to separate the sandstone into two parts, one coarse and heavy which falls quickly to the bottom, the other light and finely divided, which remains, for a time at least, suspended in the water. But this finely divided mud will in the end also sink to the bottom, and while it is settling we will examine the coarser part.

Dry the coarse sediment. The first thing we notice is that the dried mass consists of grains which have little tendency to stick together. They may look, when untouched, as if they formed a solid heap, but a gentle shake, or a touch with the point of a knife, is enough to make them fall apart. Now separate a few of the grains, and examine them with a pocket lens. Some are angular, some have their points and edges a little rounded off, and some few perhaps are well rounded. Like the rock out of which they came they have a yellowish or brownish colour. Place a few of the grains in the palm of the hand and rub them about with the fingers, they have a harsh and gritty feel.

Put some of these grains in a small beaker and pour over them a little dilute hydrochloric acid, which should be colourless. Boil this for five minutes with care not to break the glass. Now filter and put aside the filtrate, i.e. the liquid which has run through, marking it No. 2.

Wash what remains in the filter well with water and

dry it. It consists of a number of grains which readily fall apart from one another. Lay a few of them on a strip of clean glass, and examine them with a pocket lens. As far as shape and size go they are exactly the same as before boiling, but they are now almost perfectly white in colour, and we can see that they consist of a clear, nearly transparent substance, very like glass to look at. It is, however, very easy to show that they are something different from glass. Drag a few of them over the glass with the blade of a knife, pressing them firmly down as you move them, and you will see that they cut small but perfectly distinct scratches on the glass. They are therefore something harder than glass itself.

If the student should possess a microscope fitted with a 'polarizing apparatus,' he may detect another very important difference between these grains and glass. Pound down a little glass into grains of about the same size as those we have got out of the sandstone and view them under a low power, they are seen as transparent objects on a light ground. Now put on the polarizing apparatus so arranged that the field becomes dark, and you can now scarcely see the pounded grains of glass, and what you do see is by a little light reflected from their surface, as may be easily proved by shading the stage with the hand, when they will cease to be visible at all. Now, instead of the glass grains, put a few grains from the sandstone in their place, they shine up as bright spots on the dark ground, and several of them may be brilliantly coloured, the tints changing as you turn the slide about ¹.

¹ This result is seen still more distinctly if the sandstone grains are mounted on the glass strip in Canada balsam and covered with a piece of thin glass.

It is plain, then, that the sandstone grains have a different effect on a certain kind of light from that which glass grains have. Now, so far as we know, it is only *crystalline* substances which have this effect upon light. What a crystalline substance is as compared with a non-crystalline substance in other respects we shall learn by-and-by. Meanwhile we learn that the grains of sand are, so far as light is concerned, of a crystalline nature, and grains of glass are not.

If now we take a little sea-sand, or some of the 'Calais sand' that is used for scouring, and treat it in the same way, we shall find that this too consists of a glass-like transparent substance in ordinary light, and shows exactly the same appearance in the polarized light as the grains from the sandstone. So that as far as these appearances go, and as we shall learn presently in other respects also, the two are exactly alike, and are therefore composed of the same material. Whence we learn that a sandstone, as its name implies, is a mass of sand-grains hardened into a stone, but we have yet to learn what binds the grains together. The material of which both the loose grains of sand and the grains from the sandstone are composed goes by the name of QUARTZ.

We will now turn to the hydrochloric acid in beaker No. 2, in which the quartz grains were boiled. Recollect that before boiling the grains were yellow or brown; the boiling turned them white, but did not, so far as we could judge, alter them in any other respect. The colouring matter must therefore have been something coating the outside of the grains, which the boiling removed and which is presumably dissolved in the acid. The acid, in fact, which was colourless to begin with, is now of a pale yellow colour. We must now try and find

out by chemical means what this colouring matter is made of. Divide the fluid into two parts. To one of these parts add a solution of ferrocyanide of potassium—the fluid turns to a deep Prussian blue colour. To the other part add a few drops of strong nitric acid and warm—the colour deepens and becomes a brownish yellow. Now add ammonia till the liquid smells of it—a brown precipitate is thrown down of the colour of iron rust. Both these tests indicate the presence of iron, and we conclude that the colouring matter of the grains of the sandstone is a compound of iron.

Next we have to look at the beaker of muddy water No. 1. After a lapse of twenty-four hours at the most, the greater part of the mud will have reached the bottom, the water above being only slightly discoloured. The settleings are so light and fine that they are apt to be disturbed if the water be *poured* away, and it is best to draw it off by a siphon. The simplest and safest plan, though it takes some time, is to get one or two long cotton wicks such as are used in a spirit-lamp, and after soaking them in water, hang them over the edge of the beaker, so that one end is just above the mud inside and the other hangs outside to a lower level than the beaker. The water will pass gradually away through the wicks over the edge of the beaker and into any basin near which it is placed, and this without the slightest disturbance of the mud. Or if we would use a quicker, but somewhat rougher method, we may take a piece of soft glass tubing a quarter of an inch in internal diameter, and hold it in a gas flame at a point nearer one end than the other, turning it quickly round, so as to heat all sides equally; it will soon soften and may then be bent into the form of a V; slip a little bit of elastic tubing on to the end of the longer leg and put a pinchcock on to the

tubing; hold the tube with its bend downwards and fill it with water; when full, close the pinchcock, invert the tube and place the shorter leg in the beaker with its end just above the layer of mud and open the pinchcock gently, the water will run off, and when it is nearly all gone you remove the siphon. Place the beaker some distance above a Bunsen flame turned low, so as to dry the sediment slowly.

The first thing we notice about the sediment is, that unlike the quartz grains, it cakes together into a coherent mass. When rubbed about on the palm of the hand, it has a soft mealy feel very different from the harsh grittiness of the quartz grains. When dragged over a glass plate by a knife, no grating sound is heard and the glass is not scratched. It may happen indeed that by some carelessness a few quartz grains get entangled amongst the mud, and so a few scratches are produced, but then it is easy to see that it is not the mass of the sediment that does it. Place a little of the mud in the palm of the hand, add a drop of water, and work the two together with a knife. The mixture is plastic, that is, it can be moulded into any shape we choose, and will retain any shape we give it. The stuff is what we call in everyday language *clay*. What is its true nature and composition we shall learn hereafter.

This clay, like the quartz grains, is brown or yellow in colour. Like them it may in most cases be turned to a white colour by boiling with hydrochloric acid, and the resulting liquid can be shown as before to contain iron.

We have now satisfactorily made out this much about our impure sandstone. It is a mixture of quartz and clay, and the grains of both ingredients are coated with a film of some compound of iron, which gives them their brown

or yellow colour. When the staining matter is dissolved off by acid they are both pure white and the quartz is semi-transparent. Besides these ingredients we may often notice, amongst the quartz grains or clay, little spangles of a white glistening substance. This is what is called *Mica*.

The amount of clay we obtained from the sandstone is probably not very large. To make ourselves more familiar with the substance as it occurs in hard rocks, we will next examine a piece of roofing-slate which is for the most part composed of it. Pound a bit of roofing-slate and treat it in exactly the same way as we treated the crushed sandstone. In this case there will be no large grains of a different character from the mud, but only pieces of slate which we have not succeeded in breaking up, while the sediment that settles down from the muddy water will be found to possess all the properties of clay, as already observed in the sandstone, and there will be a large quantity of it. During the process we shall also become aware of another property of clay which the small quantity present in the sandstone scarcely enabled us to recognize. Whilst working the pounded rock in the mortar, a very strong earthy odour will be perceived; clay gives off this smell when wetted, and even when slightly damped by being breathed upon.

It is not always possible to remove all the colour from the clay obtained from roofing-slate by merely boiling in acid. This is partly because the particles are so fine and closely packed together that all our pounding and rubbing is not sufficient to separate them one from the other, besides which there are other colouring matters present which are not entirely removable by the acid. The clay, however, is somewhat bleached, and the acid after boiling is found to contain some iron.

If the slate be very rough, we may possibly find amongst the coarser stuff some grains which we recognize as quartz and others which are clearly different, usually with a dull milky look and not transparent. Most of these are bits of a substance called *Felspar*, which we shall soon have to say more about.

On the other hand, we may find sandstones which have practically no clay in them at all. Red sandstones are often free from clay, which is the reason why we should not choose them for our first experiments. The colouring matter in them may be laid on so thick that it binds the grains of sand loosely together without the aid of clay, and we shall find that it will all dissolve in the hydrochloric acid and leave only clean white quartz grains. Other sandstones have not any colouring matter, but the grains are bound together very closely—by more of the same quartz as they are made of. In this case the rock will be very hard. These harder sandstones, especially if their grains are large, are often called *Grits*. There is only one thing that is found in all sandstones, and that is quartz-grains.

LESSON III

WHAT QUARTZ IS MADE OF. THE MEANING OF
CHEMICAL ELEMENTS AND COMPOUNDS. DEFINITION OF MINERALS. DIFFERENCE BETWEEN
MINERALS AND ROCKS. HOW TO KNOW
MINERALS. WHAT CLAY IS MADE OF. WHAT
COLOURS SANDSTONES AND CLAYS

What Quartz is made of. The simple experiments we went through in the last lesson showed us that sandstone consists mainly of two substances, quartz and clay, mixed together. It will naturally occur to us to ask whether the quartz and clay themselves can be shown to be made up of other more simple substances.

They can, but not by a simple experiment, not by mechanical means. The successful process is one which requires some of the best resources of the chemist, and to him we must go for information as to his results ; and very remarkable and instructive results they are.

If we take some of our quartz grains to a chemist to analyze, he will find out by chemical processes what substance they are made of, and this substance he will call silica. We called it quartz, because we found it crystalline ; he calls it silica, because of its chemical properties, whether it is crystalline or not. If we then ask him if he can split it up into anything simpler, he will tell us he has been able to get out of it a brown

powder, which he calls silicon because he gets it out of silica, and the well-known oxygen gas.

But farther than this no chemist has been able to get. After trying all possible methods that can be thought of, nothing but silicon can be got out of silicon, and nothing but oxygen out of oxygen. The chemist therefore calls these substances *elements*.

He would have us note that silica is something quite different in its characters from other silicon or oxygen, of which it is composed, and that this is a very usual thing when a substance is separated into its elements.

In the next place he would tell us that as silica can only be split up by chemical means, so by chemical means alone can the elements be reunited. You cannot get silica by merely mixing together silicon and oxygen. If, for instance, you put some silicon into a bottle containing oxygen, and shake them up together, or do anything you like to bring them close together, you will still have silicon at the bottom and the rest of the bottle full of oxygen, and you will not get silica. He would explain this by stating that in silica the elements silicon and oxygen are much more closely bound together than in a mixture, and in quite a different way, so that the result is to form a substance silica, totally different in all its special characters from either of them. Such a substance he would call a *chemical compound*, as distinguished from a *mechanical mixture*.

He would further tell us that if we take 60 parts by weight—pounds, grammes, or whatever they may be—of silica, there are always in them 28 parts by weight of silicon, and 32 parts by weight of oxygen; and this he would explain by saying that it was a fixed rule with all chemical compounds, that the weights of the elements which make any one of them are always in a definite

proportion ; that whenever oxygen and silicon combine chemically the weight of the oxygen : weight of the silicon :: 16 : 28 or :: some multiple of 16 : some multiple of 28. That in the case of silica—

$$\begin{aligned} \text{Weight of silicon : weight of oxygen} &:: 28 : \text{twice } 16 \\ &:: 28 : 32 \end{aligned}$$

These numbers 16 and 28 are called the *atomic weights* of oxygen and silicon.

All this the chemist would express shortly by writing for silica, SiO_2 ; Si standing for 28 parts by weight of silicon, O for 16 parts by weight of oxygen, and the 2 under the O showing that in silica the oxygen is in the proportion of *twice* 16. SiO_2 is called the chemical formula for silica.

Chemical Compounds and Mechanical Mixtures. It is so important clearly to realize the difference between chemical compounds and mechanical mixtures, that a word or two more may be said on the subject. Suppose we take some loaf sugar and some pure white marble, bring each to the finest powder by grinding and sifting, and then mix them thoroughly together. The two may be mixed most intimately, far more closely than we could mix the oxygen and silicon in the experiment suggested a little way back ; but in spite of this it is only a mixture after all, and not a chemical compound. The eye will not tell us that this is so, but other senses will. If we put a little into our mouth, we find out by the taste that there is sugar in the stuff, but the tongue detects a certain grittiness that suggests that there is something besides sugar, and in a short time we notice that it does not all melt away, as it would if it were all sugar. If, as a further test, we put some into water, the sugar will dissolve, leaving behind something which we

could show was powdered marble. In this way we can prove that it is a mixture of two things, sugar and marble, not a substance totally different from either produced by the chemical union of the two.

These mechanical mixtures differ also from chemical compounds in the fact that the ingredients in them can be mixed in any proportions, and not only in definite proportions, as in chemical compounds. Thus in our earlier example we may put together 28 parts of silicon and 40 parts or 48 parts, or any number of parts, of oxygen, and if a chemical combination takes place, only 32 of the parts of oxygen will be used to make the compound, and the other 8 or 16 parts, as the case may be, will remain as they were.

Mechanical mixtures are also easily made, and in most cases easily separated, but it is different with chemical compounds; some special action, or *reaction* as it is called, must take place between the ingredients before a compound can be formed, and another must be brought about before they can be separated again. The putting together of two ingredients to form a compound is called *synthesis*, and the separation of a compound into its ingredients or elements, as the case may be, is called *analysis*. If we determine the nature only of the ingredients, we call it *qualitative analysis*, and if we determine also their relative proportions by weight, i.e. the percentage composition, we call it *quantitative analysis*. Chemical compounds are very seldom, if ever, found in nature absolutely pure, that is to say, consisting only and solely of the elements which combine chemically in the proper proportions. Everything *mixed* with them is reckoned as an impurity.

The number of chemical compounds possible depends in the first place upon the number of elements in nature,

and in the second place upon the number of ways in which they can chemically combine in multiples of their atomic weights. Neither of these two latter numbers is indefinite. There are nearly 70 elements known, and each is found to combine with only certain of the others, and in only a certain number of multiples of the atomic weights. Each element has a symbol, corresponding to Si or O, which represents also the proportion by weight in which it combines, and the chemical formula of any compound is formed in the same way as in the case of silica, by writing one after the other the symbols for the elements of which it is made up, and putting small figures beneath each symbol to show whether the corresponding elements occur once, twice, three times, and so on, in that proportion.

Minerals. There are many other substances in the earth's crust which, like quartz, are chemical compounds, made up always of the same elements, and containing always the same percentage by weight of each element. All these substances are called minerals.

We can form many other chemical compounds in our laboratories, but we do not call these minerals, because they are artificial products.

Other chemical compounds are formed in the bodies of animals, and by plants, but we do not call them minerals, because they are made by living creatures; only sometimes, after they have passed out of the living creatures and have been buried in the earth, are they included in our lists of minerals.

We define a mineral to be—*a definite chemical compound formed naturally, and not formed solely by the agency of living animals and plants.*

We may just notice here that minerals often take shapes of great regularity and beauty, which are called

crystals. These crystals are generally bounded by smooth faces, which are often polished and glistening. Crystals of quartz, for instance, are frequently of the shape shown in Fig 1. It is like a tower with six upright faces, surmounted by a dumpy six-faced spire. More will be said about crystals further on.

Difference between Minerals and Rocks. Sandstone is evidently not a mineral. It is obviously a mechanical mixture, and not a chemical compound, of quartz and clay. For, in the first place, the percentage of these two

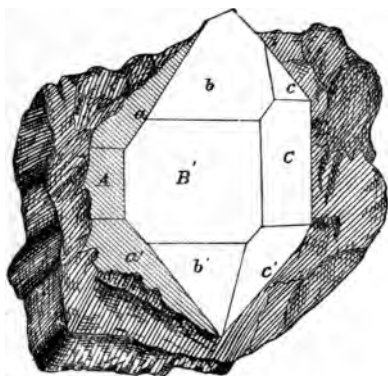


FIG. 1. QUARTZ-CRYSTAL.

substances in any sandstone is far from being the same in all other sandstones; some are nearly all quartz, some contain a large amount of clay, and it would be scarcely possible to find two sandstones which contain the same proportions of these substances. In the second place, sand-

stone is quartz *and* clay, not a substance altogether different from either.

Sandstone we call a *ROCK*, and what we have found to be true of sandstone we shall find to be true of nearly all rocks. *Rocks are mechanical mixtures of two or more minerals.* The exceptional cases in which a rock is made up of a single mineral only are very few indeed.

How to know Minerals. The first step, then, towards finding out what the earth's crust is made of, is to learn what are minerals found in it, and to do this we must

be able to know these minerals when we have them to examine. As an instance, let us see by what means we could ascertain whether a mineral which we were dealing with was quartz or not.

First, is it composed of silica? To learn this we must have it analyzed.

But secondly, even if it be composed of silica, it does not follow that it is quartz. Silica takes several different forms, of which quartz is one. Quartz we have been told is crystalline, so we next try if our specimen is crystalline.

But even if we find this to be the case, it does not quite settle the question, for if it were only partly crystalline, or contained certain impurities, it would go by another name. How then are we to find out whether this is so or not? Here is one way. These things will affect the relative weight of the mineral, making it lighter or heavier for the same-sized piece, so the different varieties will have different 'specific gravities¹,' that of quartz being 2.6.

We might then proceed thus. Find by analysis if the mineral consists of silica. Find if it is crystalline. Find if its specific gravity is 2.6. If we find all these three things to be the case, the mineral can be nothing else but quartz.

This, however, would be a tedious method, and fortunately we can generally say pretty safely when a mineral is quartz without taking all this trouble. One thing

¹ The specific gravity of a substance is the number obtained by dividing the weight of a piece of the substance—say, a cubic inch—by the weight of the same-sized piece, in this case a cubic inch, of water. This latter is found by weighing the piece of the substance suspended in water; the loss of weight, as compared with the original weight, is plainly equal to the weight of the water whose place the substance occupies.

that struck us about quartz was its great hardness—it scratched glass easily. This alone would distinguish it from many other minerals. Again, if we take a bit of quartz larger than the grains out of the sandstone, we shall find that it breaks with an uneven surface, like glass, while many other minerals break in a very different manner, as we shall presently see. Here, then, is another character which distinguishes quartz from many other minerals.

Qualities such as hardness, way of breaking, specific gravity, and such like, are called PHYSICAL PROPERTIES. Now, in many minerals these physical properties are so well marked and, *when taken altogether*, so utterly different from those which belong to any other mineral, that we may safely say that a specimen which possesses this or that set of physical properties is this or that mineral.

Thus, in the case of quartz, if we find a mineral which scratches glass easily, and it is a *common* mineral, obtained, let us say, from the broken or rounded grains of a piece of rock, it is most likely quartz, since quartz is the only *common* mineral that will do this. If, in addition, we find the surface when broken is irregular, we may be still more certain, because most of the other even less common minerals that will scratch glass break in a different manner, and we may thus conclude, in the great majority of cases, that the grains are quartz, and the rock is a sandstone. We shall learn by-and-by how to deal with those few cases in which these tests might lead us wrong.

What Clay is made of. We have now to come to a rather more difficult matter—the composition of clay and what it has been made from. We have already seen that it is very different in appearance to quartz, as it

is in very fine powder, and we cannot get a bit of it like a crystal to examine. Nevertheless, there *is* a mineral which is crystalline, and which when pounded up very fine produces a powder which is very like true clay, and which in common language would be called a clay.

This mineral is called *Potash felspar*, or *orthoclase*, and the student must procure from a mineral-dealer or elsewhere a specimen of it; not a choice, beautiful example, but a common bit which he will not mind breaking up and otherwise experimenting upon. It will probably be of a dull yellowish or pinkish colour, and will have a shape something like Fig. 2.

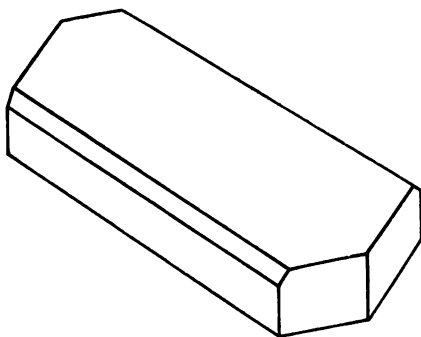


FIG. 2. ORTHOCLASE FELSPAR.

It will be found to scratch glass, but not so easily as quartz, and a piece of quartz will scratch it. As both minerals are hard, some force must be used. It can be just scratched, but only with considerable difficulty, with a strong knife-blade, and quartz cannot be. It is therefore not quartz. It also breaks in a different way from quartz. There are straight parallel cracks running through it, and if a knife be placed on one of these

cracks and smartly tapped with a hammer, the mineral will break along it, and the broken surface will not be uneven, as it was with quartz, but smooth, polished, and glistening. What is more, the little plate thus detached can be itself broken up into thinner plates, each bounded by smoothed polished faces, and these faces are all parallel to the smooth face along which the plate was first separated.

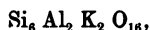
This breaking of the mineral in certain directions more easily than in others, and the faces thus produced being smooth and polished, is another physical property of certain minerals, called *crystalline cleavage*.

This mineral we are now dealing with, that is, potash felspar, may also be cleaved in another direction, though not quite so perfectly. The two directions of cleavage are at right angles to each other, so that when a cleaved piece is set down on a table on one of the smooth surfaces, two of the sides will appear to be upright.

If potash felspar be pounded very finely, the powder, if mixed with water, is quite plastic enough to make it a clay in the language of common life; but as it is not a true clay, it may be called *felspathic mud*. How potash felspar has been naturally powdered down and reduced to this clayey state we shall explain presently.

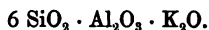
But the potash felspar may be not only ground down mechanically, but it may also undergo chemical alteration, to understand which we must inquire as to its composition.

The chemical composition of potash felspar is represented by the formula



where Al stands for 27.4 parts by weight of the metal

aluminium, and K for 39.1 parts by weight of the metal potassium ; but it may also be written—



In the first formula we simply write the component elements one after the other, and as these are more numerous than in silica we get a longer formula, but it is of the same kind as that already given for silica, and from it we learn that in 557 parts by weight of potash-felspar there are :—

$$\begin{array}{rcl} 6 \times 28 & = & 168 \text{ parts of silicon,} \\ 2 \times 27.4 & = & 54.8 \text{ parts of aluminium,} \\ 2 \times 39.1 & = & 78.2 \text{ parts of potassium,} \\ \text{and } 16 \times 16 & = & 256 \text{ parts of oxygen.} \\ & & \hline & & 557 \end{array}$$

The second formula requires more explanation. SiO_2 , as we know, is the formula for silica ; Al_2O_3 is the formula for a chemical compound of aluminium and oxygen, called alumina ; K_2O is the formula for a compound called potash. The second formula then states that potash felspar may be looked upon as a compound of silica, alumina, and potash, and it is hence said to be a silicate of alumina and potash.

Now when chemical compounds combine, they unite, as elements do, only in definite proportions, by weight ; what these proportions are is found by adding together the weights of the elements in the compound, and the weight so obtained, corresponding to the atomic weight of an element, is called the combining weight of the compound ; and the compound will only unite with others either in this proportion or in some multiple of it. Now for silica, Si represents a weight of 28 of silicon, O_2 a weight of 32 of oxygen, the combining weight of silica, or, as it is sometimes called, the *equivalent* of silica, is therefore $32 + 28$ or 60. In the same way we find

28 *First Lessons in Modern Geology*

the equivalents of alumina and potash to be 102.8 and 94.2 respectively. Now in the formula the 6 before the SiO_2 applies only to the silica, as there is a full stop after the SiO_2 , and shows that there are six equivalents of silica, one of alumina, and one of potash. From this it is easy to see that in 577 parts of potash felspar there are

$$\left. \begin{array}{rcl} 6 \times 60 \text{ or } 360 & \text{parts of silica} & = 64.6 \\ 102.8 & \text{parts of alumina} & = 18.4 \\ 94.2 & \text{parts of potash} & = 17.0 \end{array} \right\} \text{per cent.}$$

557

Now when the substance thus constituted is exposed to the action of the air and rain, it becomes slowly altered, and one of the results is the production of a soft white plastic substance whose chemical composition is



which corresponds to the following percentage composition :

silica	46.3
alumina	39.8
water	13.9

H being the symbol for hydrogen whose atomic weight is 1, and H_2O the symbol for water whose equivalent weight is therefore $2 + 16 = 18$.

From this it appears that, under the action of the weather, two-thirds of the silica and all the potash have been taken away and two equivalents of water have been added. Chemists speak of compounds which contain water in a state of chemical combination, as *hydrated*, and thus call this white substance a hydrated silicate of alumina. It is this of which the best china is made, and it is called *Kaolin* or *China-clay*.

The clay of everyday speech then is one of the two kinds of material above described : one, felspathic mud,

is potash felspar which has been finely powdered, but not decomposed; the other, kaolin, has been formed out of the felspar by chemical decomposition. The clay we get out of sandstone may consist wholly of one or other of these substances, generally it will be a mixture of the two. It is not always easy to tell kaolin from felspathic mud, but pure kaolin may be distinguished thus:—Moisten a little with water and press it with a knife into a thin plate with a sharp edge. Dry the plate, and hold it in a pair of forceps in a steady blow-pipe flame just in front of the tip of the blue inner flame. If it be felspathic mud, or a mixture of felspathic mud with kaolin, the sharp edge will just be fused and rounded; if it be pure kaolin no exposure to the blow-pipe flame will fuse it. To be certain of the result the student must be sure that he can manage his blow-pipe, and the best way will be to try if he can fuse the tip of a very small sharp splinter of potash felspar itself; if he can, he has the requisite mastery of the flame.

There are other minerals besides potash felspar which yield kaolin by decomposition, or can be ground down into something resembling felspathic mud. They, like it, are silicates of alumina and potash or soda, with different multiples of the equivalent weights; but a very large part of the clayey substances we commonly meet with comes from potash felspar.

The rough test we shall for the present use to determine whether any substance ought to be called a clay will be this. Pound a little of it, if it be hard, and work it up with water in a mortar, or by means of a knife on a slab of stone; if it works down almost entirely to a soft plastic mass, it is one of the two kinds of clay.

The Colouring Matter of Sandstones and Clays. Let

us now ask about the compound of iron which gives the brown or yellow colour to most sandstones.

We all know how liable iron is to rust, and we also know that the rust which forms, say on clean fire-irons left in a damp place, is very much of the same reddish-brown colour as many sandstones show. This rust is a chemical compound of iron, oxygen, and hydrogen. Its formation on the surface of the iron is owing to the presence of moisture in the surrounding atmosphere, which is composed as we know of oxygen and nitrogen. The process is somewhat complicated, the result being that some of the oxygen and some of the water in the air unite chemically with some of the iron and rust is formed.

Now this rust is called by chemists a *hydrated ferric oxide*, or more shortly a ferric hydrate, because it is a combination of ferric oxide with water. A compound of any element and oxygen alone is called an oxide of that element. The commonest oxide of iron is called by more than one name: *ferric oxide* is one name; another is *peroxide*, because there are other oxides of iron and this contains the highest percentage of oxygen; a third is *sesquioxide*, because three equivalents of oxygen are united in it to two equivalents of iron, or $1\frac{1}{2}$ times (sesqui) as many.

It is found in nature as a dark or blood-red substance, to which on this account the name *Haematite* is given. Its composition being Fe_2O_3 where Fe stands for 56 parts by weight of iron, there must be in every 160 parts of it:

$$\begin{array}{r} 3 \times 16 = 48 \text{ parts of oxygen,} \\ 2 \times 56 = 112 \text{ parts of iron.} \\ \hline 160 \\ \hline \end{array}$$

This substance combines with water in several different

proportions, and if we take some of the grains out of our sandstone to a chemist, he will tell us that the colouring of them is generally due to the presence of one of these hydrates. Such a hydrate when found in bulk as a mineral is called *Limonite*, and the different colours are related to the different proportions of water.

In the vast majority of cases the colouring matter, not only of sandstones, but of other rocks as well, is some compound of iron that coats the outside of the grains; and of the various compounds which play the part of colouring matter, ferric hydrates are the commonest.

But sandstones are not always yellow or brown. If we go to a very deep quarry, the stone changes its colour as we go deeper, and at the bottom it is greyish or bluish. One colour passes gradually in some measure into another, and many of the blocks that come from the lower part of the quarry are grey inside and reddish-brown outside. This is particularly the case if, as usual, the blocks have been bounded by cracks, and we find also that the cracks which run from the surface of the block down into the middle of it are each of them bordered by a band of the same reddish-brown colour.

It is clear enough that the stone is reddish-brown wherever air and water can get to it, as near the top and along the sides of cracks, and grey when air and water cannot reach it. The natural conclusion is that the grey tint is changed into reddish-brown by the action of air and water.

Now if we take a piece of the grey rock to a chemist, he will tell us that it contains a compound of iron called *carbonate of iron* or *ferrous carbonate*, the chemical formula of which is



where C stands for 12 parts by weight of the element carbon. Ferrous carbonate is white and does not colour the rock by itself, but it is often accompanied by impurities derived from the decaying parts of plants or from other sources, and to these the grey colour is due.

But when ferrous carbonate is exposed to the air it undergoes change. Its formula may be also written FeO , CO_2 , showing it to be formed by the union of carbonic dioxide represented by the formula CO_2 , and ferrous oxide represented by FeO , which cannot exist by itself, but when oxygen is supplied to it from the air it becomes Fe_2O_3 , or ferric oxide. While the carbonic dioxide goes off in the form of gas, the ferric oxide at the same time unites with the moisture to form a ferric hydrate. The colour given by this substance is so strong that it completely overpowers the original grey tint, and the rock turns reddish-brown or yellow. In a word, the change in the colour of the rock is simply caused by the rusting of the iron which it contains.

Sandstones are much more commonly rusty-coloured than clays. The reason is that sandstones are full of open crevices which allow air and water to find their way into and through the rock. Clays, as a rule, are much closer in the grain, and in them the rusting of the iron either does not take place at all, or extends only a short way into them. Still, we shall find that in most clay-pits the top part is brown, while the bottom may be blue or even almost black clay, and this change of colour is due to the same causes as in the case of the sandstone.

To sum up our results, we have divided the sandstone into two parts:—

1. Grains of sand: coarse, hard enough to scratch glass, do not stick together, composed of quartz.

2. Clayey matter: fine, soft, sticks together into a plastic mass, composition variable, but always containing alumina, being either kaolin, powdered potash felspar, or allied mineral.

The grains both of sand and clay are coated with a thin skin of ferric hydrate, or iron rust, which gives them a brownish colour.

The sandstone is a *mechanical mixture* of sand and clay, but sand itself is a *chemical compound*, as is also the clay.

LESSON IV

HOW SANDSTONES AND CLAYS ARE PRODUCED.
WHAT THEY WERE MADE FROM. THE WEATHERING OF ROCKS. DENUDING AGENTS. BEDDING AND HOW IT WAS CAUSED. DIFFERENT KINDS OF SANDSTONES AND CLAYS, AND SOME OF THE STRUCTURES FOUND IN THEM

How Sandstones and Clays are produced. All that we have learned so far might have been found out without putting a foot out of doors. Some one might have brought us in pieces of sandstone and clay and we might have examined them in the house. This has taught us a good deal that will be very useful, but it is only a very small part of what we have to learn even about sandstones and clays.

We must now, then, take our hammers, and go out into the field and see what these rocks are like—not in little hand-specimens, but—on the large scale in quarries, cuttings, and cliffs. Sooner or later we shall light on things that will open our eyes to facts that no amount of indoor work would have taught us.

Most of the stones that we break with our hammer have nothing curious inside them, but in some parts of the country at least we shall be certain after a time to find a block of solid rock, which when we break it open shows us in the very heart of it what looks very like

the leaf of a plant, the shell of a shell-fish, or the bone of an animal. But is it really such? or is it only a sort of fancy model, that is generated in the rock itself, and has never formed part of any living thing? So men used for a long time to think. But when we look closer and find all the little details of form and structure even as seen by the microscope repeated in many of these *fossils*, as we call them, just the same as we find them in living animals and plants, we can no longer doubt that they are no pretence, but really belonged at one time to the things which they represent.

How then could the fossil have got there? Why it must be like an oyster buried in the mud. It can only have got there in one way. The animal or plant must have been made first, and then the stuff of which the rock consists must have been gathered round the relic and have buried it¹. Just as in the building of a house we might drop coins or other articles into the mortar while the wall was being laid, and there they would remain to tell us that the house was built after these coins were made, so the parts of plants and animals that were living at the time, or a little before, have been enclosed in the rocks during their process of formation, and give us proof alive that there was a time, namely before these things were alive, when no such rock was there, and that they have been produced in some way at a later date. Some facts which we have learnt give us a clue to the manner in which their production was accomplished.

How Sandstones and Clays were made from. Now we have learnt that sandstones and clays were not made all at once, but each one at some particular time, and that any one sandstone or clay may have been

made of animals that bury themselves in mud or solid rocks.

made out of an earlier one of the same kind. But going back this way we must at last come to a sandstone and clay which were made out of something different. Now clay, as we have seen, is formed out of felspar, and sandstone out of quartz, but where are we to look for the quartz and felspar themselves? There are many rocks which are themselves neither sandstones nor clays, such as granite for instance, and which are made up of such minerals as quartz and felspar, not in small grains or in a decomposed state, but in good-sized lumps and in a solid condition, and these if broken up would yield the materials we want. In any case it is plain that to get a new rock of the kind we are talking about you must break up an old one, be it sandstone or granite, and for this reason we call the new ones *clastic rocks*, from a Greek word meaning 'broken.' We also call them *derivative rocks*, because they are derived from pre-existing ones.

Weathering of Rocks. How do the old rocks get broken up? If we only keep our eyes open as we walk about, we shall soon find an answer to this question. The lower part of the soil, as we have already noticed, is in many places largely made up of broken bits of stone that are exactly the same as the solid rock which lies a little lower down, and this stony part of the soil has certainly been formed by the breaking up of the layers of the solid rock. Again, in any section you will see that the top part is broken into little pieces, and further down the rock gets more and more solid. In some rocks the breaking up goes to a great depth; in parts of Cornwall, for instance, the surface of the ground is covered by a coarse powdery sort of gravel; you may dig down to a depth of many yards and find nothing else, but if you go deep enough you will come at last to

granite. The upper part of this granite is soft, and may be crumbled between the fingers into just the same kind of gravel as lies above ; but the rock grows gradually harder the lower we get, and becomes at last so solid that it takes several strong blows of our hammer to break a piece off.

If we look at the gravelly stuff we shall find that it consists mainly of grains of quartz, mixed with a mealy clayey substance, and from this clay we may pick out many bits of felspar which are crumbly and clayey outside, but still solid within. A great deal of the felspar has evidently been turned into clay, and this has reduced the solid rock to a loose mass which readily crumbles down into the sandy stuff which lies so thick under our feet. We become more than ever convinced that this is the case, when on turning over the loose matter we find amongst it lumps of granite in various stages of decomposition—some almost as firm as the solid rock at the bottom ; some in which the pieces of felspar still keep their shape, but the mineral has been changed into a soft white meal ; and so on till we reach bits in which the change of the felspar into clay is complete and the lump falls into powder at a touch.

Many other instances might be given, but they all tell the same tale. They all show us that the rocks that lie on the surface are constantly being broken up on the spot, and worked down into sand, clay, or some such loose stuff, which is just the sort of material out of which elastic rocks are produced. And do not take this for granted because it is written in a book. Look well around you and see whether it is not true ; for be sure that unless your own eyes convince you that this is going on everywhere, nothing will make you a geologist.

Now all we know at present about this breaking up is

that it is related to the surface of the ground, for the nearer any part of the rock is to the surface, the more in most cases is it affected. It must then be some surface agent that brings it about, so we say it is due to the action of the weather, and we speak of the process as the *weathering of the rock*. We must now inquire how the weather is enabled to break up rocks. When we talk of the weather we mean, is it hot or cold? is it fine or rainy? and it is just the cold and the rain that have the most power in breaking up the rocks.

Action of Frost. When the cold amounts to freezing we can easily see how powerful it is to break up things. Suppose we have a tall vessel of strong iron with a large open mouth and partly filled with water, and we make a mark on the side of it just at the top of the water. We then freeze the water. It will be found that the top of the ice is above the mark. The ice takes up more room than the water. If we laid a bit of cardboard on the top of the water, it would have been lifted when the water froze—the ice would have pushed it up. And we can prove that the push is a strong one in this way. Take a hollow iron ball, fill it with water through a small hole, and then close the hole with a screw. Place the ball in a strong freezing mixture. After a time a sharp crack will be heard, and the ball will be found broken into two or three pieces. The ice, when it forms, must have more room; it can get it only by breaking the iron, and it pushes against the shell that is holding it in with such force that it rends cast-iron half an inch thick. The same action cracks our bedroom crockery and water-pipes during a frost. Now many rocks are full of cracks and crevices in which the water lodges, and against the sides of these when it freezes it pushes with this powerful thrust till large blocks are broken off. Wherever

there is frost the work goes on. Perhaps the best places for seeing this result are in mountainous districts and by the sea cliffs, where the pieces that break off can fall away. Below every crag and many a cliff enormous masses of loose blocks of rock are piled up in heaps, which are called *screes* (see Fig. 3). Most of these blocks have come from the crag or cliff above, and have been



FIG. 3. SCREES ON MOUNTAIN-SIDE IN THE PASS OF LLANBERIS.

broken off by the frost. When the same action goes on on horizontal surfaces, the broken-off pieces have to stay where they are, and thus form the fragments that work up into the soil.

Action of Rain in Weathering. Powerful as frost is, it can only do mechanical work ; it could never alter

a felspar into clay ; so it cannot be this alone that breaks up the granite as we have described. It must be something too that penetrates further into the ground than frost can. The agent we want is rain. From what we have learnt about the composition of clay, we know that water must somehow reach the felspar that clay is made from. It comes from that part of the rain that sinks into the ground. And this water is not pure. It carries with it in solution some of the oxygen from the air, and some carbonic dioxide and other ingredients which it obtains, in part from the air and in part from the decaying rubbish that may be lying on the surface of the ground. These agents do the chemical work required, and of course in doing so break up the rock. It is the same rain-water that alters the colours of the sandstone. These agents, frost and rain, act together and help each other. The rain dissolves a little of the rock and fills the crevice with water, the frost breaks open the crevice wider and next time more rain gets in, and so on till a large piece breaks off, and then the solid rock below begins to be attacked. If you go to a quarry during a frost you will find the crevices between the pieces at the top filled up with ice.

Denuding Agents. In whatever way the surface of a rock may be broken up, the result is to produce a quantity of loose stuff, which is called by the general name of *débris*, a French word, and pronounced as such, meaning broken down. The next step towards the formation of a new rock is the removal of this *débris* and its transport to some place where it can rest. The process of this removal is called *Denudation*, because the solid rocks below are thus laid bare, or would be if fresh *débris* did not in the meantime form ; and the agents that do this work, such as rain, and other

forms of moving water, or wind, are called *Denuding agents*. In this term is included also the production of the *débris*, which is often formed and carried away at the same time.

The two principal agents which we must notice are *Rain and Rivers* and the *Sea*. The sand or clay that is produced by weathering cannot always rest where it is made. Every shower of rain washes it further and further down the hill-slopes, and at last it finds its way into some brook. There it is swept on till it either enters a pond and the water comes to rest, and the mud settles down and forms a layer over the bottom; or it passes on to a larger stream still carrying its burden, and so on to the river, which may at last bear the muddy water out to sea, and let the deposit settle there.

To observe the action of the sea in breaking up rocks and producing sand we must go to a shingly part where the pebbles are made of quartz. Besides the pebbles there is much sand; we can trace a gradual passage from pebbles as large as a fist or larger, through pebbles of smaller and smaller size, down to fine sand, and we can see at high tide the waves tossing pebble against pebble, till they break in pieces, and then grinding the fragments smaller and smaller till they bring them down to sand. A more striking instance of the work of the sea is to be seen on a coast facing an open ocean and fringed with steep cliffs. During a heavy gale the waves rush in with such violence that they can toss about blocks of rock some tons in weight as though they were mere pebbles. Such blocks lie in plenty at the foot of the cliffs from which they have been broken off by frost; they are dashed against the cliff-face, and by this pounding and battering it is from time to time shattered and worn back. The same kind of work goes on and the land is

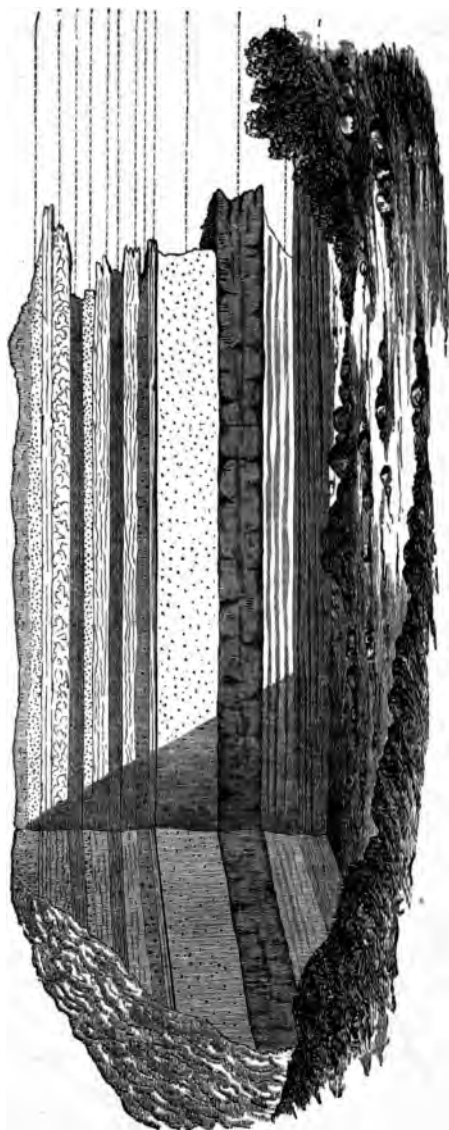


FIG. 4. QUARRY OF STRATIFIED ROCKS.

eaten away very rapidly, even along the coasts of comparatively small seas, when the cliffs consist of soft rocks, as for instance along parts of the east coast of England.

In comparing the amount of denudation done by the rain and by the sea, it must be noted that the sea does the main part of its work only along the coast-line and during storms. For this reason the sum total of marine denudation is much smaller than might be imagined by one who watched it only when its action was at a maximum. Rain, running water, and frost, however, are pretty constantly at work, and they act over the whole surface of the land. They are so familiar, so quiet and unobtrusive in their action, that we are very apt to overlook their importance; but collectively they do more, probably very much more, denudation than the sea does.

Bedding. There is another point that will strike us when we come to examine many clastic rocks in quarries and cuttings. When we get down to the solid rock we do not find it one thick unbroken mass, but it is made up of a number of separate layers placed one on top of the other. Sometimes each of these layers keeps very nearly the same thickness throughout its whole length, so that the face of the quarry looks like the front of a heap of planks in a timber-merchant's yard (see Fig. 4). Sometimes the layers are more like wedges in shape, and dovetail into each other.

These layers are called *beds* or *strata*, and the rock is said to be *bedded* or *stratified*. When each layer keeps pretty much the same thickness all along, the bedding is said to be *regular* or *even*; when the thickness of the layers changes as we follow them along, the bedding is said to be *irregular* or *wedge-shaped*.

The beds may vary in thickness: in sandstone they

are usually some few feet thick, but sometimes on taking up a slab we find that we can split it with the sharp edge of a hammer into plates only a fraction of an inch thick. In clayey rocks we can sometimes scarcely make out any bedding at all, but often they may be split into layers no thicker than a sheet of paper, in which case the layers are spoken of as *laminae*, and the rock that is made up of them is said to be *laminated*.

How Bedding has been caused. We must certainly find out what caused rocks to have this bedded structure. Do you want to know how your house was built? You could learn out of books or by talking to a bricklayer, but there is a far better way. Another house very similar to your own is being put up not far off. Go and watch the men at their work. The house they are building, as far as it has been carried up, is so exactly like your own that you feel certain that the method which the workmen are using there must have been employed to build your own house. Well, will not the same plan answer in the case of the rocks? It is a structure that has been built up by nature in layers. Is she building up anything like it in layers now? Look about then, and if you find her at work at such a structure, watch her, and learn how the work is done. You cannot doubt that nature used just the same means to produce bedding in the rocks as she is now using to produce bedding or something very closely resembling it. The conclusion is even safer than in the case of the house, for men change their methods from year to year with a view to improvement, so that you cannot be sure that your own house which was put up years ago was built *exactly* in the same way as the new house now in course of erection. But we have no reason to believe that nature ever changes her methods; her laws are fixed

and do not alter, so that what she does and how she does it have remained unchanged ever since the world began to be formed.

We do get every now and then a chance of seeing nature lay down in beds the exact materials of which sandstones and clays are made. A large pond, such as a mill-dam, may be laid dry for the purpose of clearing away the mud by which it is nearly filled. The first time you have a chance go and look at such a pond while it is being cleaned out. You will find the mud is partly made of sand and partly of clay, and it is most distinctly bedded. There will be perhaps at the bottom a layer of coarsish sand, above it a layer of clay which splits up into regular laminae as thin as sheets of paper; then comes a bed of fine sand; then clay without lamination; then a bed in which sand and clay are mixed together, and so on. Except that the beds are thinner, and the materials are loose and crumbly instead of being solid, what we see is exactly the same as is shown in the face of many a quarry where beds of various kinds of sandy and clayey rock lie one upon another. The section of the mud is a copy in miniature of the section in the quarry, as far as the arrangement goes, and if we could only harden the beds a little the resemblance between the two would be perfect. We shall learn presently that nature has means at her disposal of hardening loose matter, like that at the bottom of the pond, into solid rock; and we may therefore fairly say that here in the pond the first step in the process of forming bedded sandy and clayey rocks is going on before our eyes.

And it takes but little trouble to find out how the work is carried on. As long as there is any rain to wash the mud into the brook the layer keeps growing thicker. But sooner or later dry weather comes, the supply of

mud ceases, and the layer begins to grow more solid, and to harden a little. And so when the rain comes again and more mud is brought in, it does not stick close to the last-formed layer, but makes a new one separated from the other by an even surface.

And you can see the same sort of thing by an experiment. Go to any brook after rain has been falling heavily and take up a tumbler-full of the dirtiest water. It is thick, but if you let it stand a little it begins to clear and some of the sediment sinks to the bottom. Pour off the water gently and examine the sediment. You will find it to be sandy; the water is still muddy, but if it stand long enough it will clear and the later sediment will be found at the bottom. If the whole had been left undisturbed we should therefore have a sandy layer at the bottom and a more clayey one at the top, but both are so soft and loose that we cannot make a section to see them, though they will be partly shown if one of the sides of the glass be flat.

Again, the brook will not always bring down the same kind of sediment. Heavy rain will be able to wash in coarse sand, and it will swell the brook so much that it will be fast enough to sweep such sand along. Hence after a very heavy rain the stuff at the bottom of the pond will be mainly coarse sand. And if you look at the bottom of the brook where it is shallow enough to see through the muddy water, you may see at places large lumps or pebbles of stone being rolled along there. On the other hand, gentle rain will only enable the brook to move fine sand, or may be only still finer clay, and therefore after slight showers nothing but layers of fine sediment will be laid down in the pond. All these things will be still better seen where streams run down from lofty hills. When they are flooded by rain you may

hear the stones rattling along the bottom, and when the flood-water subsides you will find them all covered over by the finer mud.

The principal difference between what we may thus see in process of formation and the rock-beds we are seeking the cause of is the matter of size. We do find in the earth's crust sandy and clayey rocks in thin beds, some coarse and some fine, which do not spread over any very large extent of ground, and such we may well conclude were actually formed in ponds or small lakes exactly in the way just explained. In other cases similar but thicker rock-beds cover many square miles of country; but all we want to explain these larger deposits are bigger lakes, and in the place of brooks large rivers swift enough to carry down sufficient sand and clay to make thick layers. In many cases the fossils found in the rocks belonged to animals that live only in salt water, and we then know that the stuff of which the rock is composed was carried out to sea; but the process in all other respects is just the same as before.

In explaining the way in which we find out how sandstones and clays were formed, we have made rather a long story of a very simple matter. But this has been done on purpose, as a sample of the general method we must pursue in the case of every rock whose origin we want to know. We shall have to hunt about and see if we can find nature at work making anything of the same kind as the rock in question, or something which if not now the same, might easily be made so by methods which we know are used by nature. Then we watch the work and see how it is carried on, after which there remains little doubt in our mind that the rock we are studying was formed in the same way.

The conclusion we have come to in the present case is

this. The material of which sandstones and clays are made was produced by the breaking up the surface of some older rock under the action of the weather. The loose stuff thus formed was carried by running water into some body of still water, such as ponds or lakes or the sea; it was there let fall, and it spread itself out in sheets over the bottom. And in a somewhat similar way we may explain the formation of rocks which originated by the action of the sea upon its bounding cliffs.

Different kinds of Sandstones and Clays. As we search from quarry to quarry we shall come across different kinds of sandy rocks. Some are made up of small grains which are all pretty much of a size: these we call simply *sandstone*. In others, some grains are very much larger than the rest, so that a freshly-broken surface has a very rough feel: these we call *grits*. In others again large rounded pebbles of white quartz or other hard rock are imbedded in a sandy or gritty paste: these are *conglomerates* or *pudding-stones*. There are also all degrees of hardness. *Sand* will not hold together; a rock a little firmer, but not solid enough to be called stone, is *sand-rock*; and from these there are all stages up to sandstones and grits that can be broken only by the blow of a heavy hammer.

The more finely-grained sandy rocks are often very evenly bedded. Frequently the surface of the planes of bedding are thickly covered by the small plates of a silvery-looking mineral called *mica*, which glistens in the sun; such rocks are called *micaceous sandstone*. The coarser sandstones are often very irregularly bedded, for irregular bedding is decidedly the rule among sandstones generally.

Clayey rocks are not all soft, but even the harder varieties usually break up and turn into mud, when

they have been exposed to the weather for a few weeks, and a very little grinding with water in a mortar will bring them down to mere sludge. Some very hard forms, like roofing slate, give way very slowly indeed under the action of the air, but can be ground down to mud in a mortar.

As a rule clayey rocks tend to be regularly bedded, and are very frequently laminated. A well-laminated clayey rock which splits evenly into thin layers parallel to the bedding is called *shale*; a similar rock containing a good deal of sand would be called a *sandy shale*. Many shales are dark coloured, which may be due to staining by the products of decayed plants, in which case they are called *carbonaceous shale*; less commonly the dark colour may be due for the most part to the products of decayed animals, when the rock smells strongly of bitumen, and is called a *bituminous shale*.

Concretions. It is not uncommon to find in rocks certain lumps harder than the rest, more or less rounded in shape, and differing from the main rock in their chemical composition. When they occur in sandstones they usually consist of more calcareous matter and are called *calcareous concretions*. They often contain the remains of numerous fossil shells which are imbedded in their substance. They are, however, commonest in clay rocks, in which case they are usually smaller, and may contain a single fossil in the middle, which gives them a peculiar shape. The following are among the commonest.

Clay ironstones. These are flattened balls hardened by a cement of ferrous carbonate. They are sometimes so flat as to be called *penny-stones*, and are abundant in association with coals. *Cement stones* differ from the last in being hardened by calcium carbonate; they are often used for making cement of, whence their name,

Septaria. The inside of some of these nodules shows a network of cracks which do not reach quite to the surface; sometimes the cracks are empty, but more frequently they are filled by calcite or some other mineral. On striking these nodules they separate into numerous pieces, whence their name. It would appear that the nodules after forming had shrunk on drying or for some other reason, and then that water holding some mineral in solution had found its way to the inside and deposited the dissolved matter in the cracks. *Balls of iron pyrites.* The mineral so called is a very common one; it is a compound of iron and sulphur, and it is so hard that it will strike fire with steel, whence the name. When it occurs in balls we find on breaking these open that they are made up of a number of fibres which radiate in all directions from a centre.

We cannot say exactly how concretions were formed. Some chemical action has been at work which has caused mineral matter to collect in certain spots. From their frequent association with fossils it is reasonable to suppose that the decay of the animals or plants has in some way brought about this chemical action, but a discussion of the precise process would be out of place at this stage of our study.

LESSON V

WHAT LIMESTONE IS MADE OF. CALCITE.

FLINT AND CHERT

LIMESTONE is so largely used for building, that if the student does not live in a district where it is quarried he will generally be able to procure a piece from a stone-mason. It is evidently made of some substance softer than quartz, for it is easily scratched with a knife, and it will not scratch glass.

Pound up a little of the rock, and put the powder into a glass beaker. Then pour over it carefully a little dilute hydrochloric acid. It effervesces briskly. After a time the effervescence ceases and the liquid becomes clear. This will come about the sooner if the acid be warmed. Add a few drops more acid and stir with a glass rod. If effervescence begins again, wait till it ceases, and then add a little more acid. Continue this till the addition of acid produces no fresh effervescence.

There will probably be some sediment at the bottom. If this be separated by washing and dried, the student will have no difficulty in recognizing that it is mainly composed of fine sand or clay, or a mixture of the two. The quantity of this sediment will depend on the impurity of the limestone; but in any case it will be far less than the powder we started with, and it is quite clear that the bulk of the constituents of the rock has in some way disappeared from view.

Take up a few drops of the clear liquid on a watch-

glass and evaporate them to dryness over a spirit-lamp; a white powder remains. Some part of the rock then is dissolved in the acid.

One of the elements of the rock that is contained in this solution may be ascertained thus. Take a piece of thin platinum wire and twist one end of it into a little spiral, and fix the other end in a piece of wood or other holder. Dip the spiral end into dilute hydrochloric acid, and hold it in the flame of a Bunsen burner or spirit-lamp, if the spirit be clean enough to make a colourless flame. On doing this the flame will at first be coloured yellow, but this colour shortly disappears. As soon as it has done so, take the spiral out of the flame and dip it immediately into the solution we are testing; then hold it just inside the flame about one-third of the way up. Short, quick flashes of a yellowish-red colour shoot through the flame. If they do not appear at the first trial, dip the coil again and hold it in the flame. If it be dipped two or three times over, the colour becomes more marked, and the whole of one side of the flame is a yellowish red.

This is the test to show the presence of the element calcium, and we thus learn that this element is one of the ingredients of limestone. Calcium is a metallic substance only obtainable by chemical means, but the common substance lime is its oxide; the formula for oxide of calcium being CaO , where Ca stands for 40 parts of Calcium by weight.

Again, it is likely that some ingredient of the stone may have gone away in the gas that was given off during the effervescence. What this gas is we may recognize thus. Take a test-tube, and a cork that will fit it; bore a hole through the cork. Take a piece of glass tube that will fit tightly in this hole, and bend it into the shape of

a U, but with one leg short and the other long, and pass the short leg through the hole in the cork. Put some small pieces of the limestone into the test-tube, and pour over them a little dilute hydrochloric acid. Then put in the cork, taking care that the end of the glass tube is clear of the liquid. Dip the long leg of the tube in a second test-tube containing lime-water. We shall find that as the effervescence proceeds the lime-water becomes milky, and after awhile a fine white powder is seen floating about in it which slowly settles to the bottom. This shows that the gas is carbon dioxide, CO_2 , a gas already noticed on p. 32.

Thus we ascertain that calcium and carbon dioxide are present in the limestone; but to learn its exact composition we must apply to the chemist, who tells us that, when pure, limestone is composed of a single chemical compound called calcium carbonate, the formula for which is



Hence we learn that in every 100 parts of limestone there are

$$\begin{array}{r} 40 \text{ parts of calcium,} \\ 12 \text{ parts of carbon,} \\ 16 \times 3 = 48 \text{ parts of oxygen.} \\ \hline 100 \\ \hline \end{array}$$

The formula may also be written



which shows that the compound is formed by the union of lime and carbon dioxide. These two substances are, in fact, constantly being obtained from it in limekilns, for when limestone is strongly heated, lime is left behind and carbon dioxide is driven off into the air. Hence the compound is sometimes called carbonate of lime.

We can now explain what happened in our two experiments. When we poured hydrochloric acid on the limestone, it formed a new chemical compound with the calcium (CaCl_2), and to do so drove off the carbon dioxide: this gas, when passed into water in which lime had been dissolved, united with the lime and formed calcium carbonate. This compound, i.e. limestone, is practically insoluble in pure water or in lime-water, so that if we do not carry the experiment too far, it falls down or is *precipitated* as a white powder.

If we want to see what happens further on continuing the experiment, we must make the milky-looking water weaker by adding more pure water, and get a fresh supply of limestone and acid in the corked test-tube; we shall then find that if we keep on letting the gas bubble up through the liquid the milkiness will gradually disappear. What has happened is this: some of the carbon dioxide has united with some of the water, in the proportion of one equivalent of each, and in this way a new compound called carbonic acid has been formed, whose formula is—



and the test-tube now contains a mixture of carbonic acid and water. Such a mixture can dissolve calcium carbonate, and the fine calcium carbonate which was floating about and making the water milky, becomes dissolved and the water is rendered clear.

Boil the clear liquid. The carbonic acid is decomposed; the carbon dioxide goes off as a gas, and water alone remains. Pure water can dissolve little if any calcium carbonate, so the greater part is thrown down and the water becomes milky again. This is very much what happens also when we boil some kinds of hard water, and then we get the kettles furred by the deposit from the

milky water. We shall find if we try that this fur is really carbonate of lime.

The important facts that we learn from these experiments are: that *water containing carbonic acid can dissolve the substance which is the principal constituent of limestone*; and that the substance so dissolved may be made by simple means to be redeposited.

Calcite. If we search about in limestone quarries, we generally find some veins of a sparry substance running through the rock, and sometimes hollow spaces lined

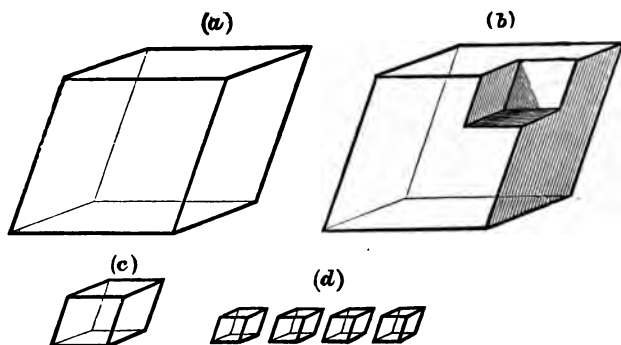


FIG. 5. RHOMBOHEDRON OF CALCITE.

with crystals; and occasionally the whole rock has a sparry texture.

These crystals are easily broken. Under a moderate blow of a hammer they fall to pieces, and the pieces are not irregular in shape, but are all very nearly alike. They are bounded, too, by smooth faces, very much the same as we found in potash-felspar; but these are more brilliant, and they glisten in the light. This we know to be an instance of crystalline cleavage, as explained on p. 26, and the smooth faces are *cleavage planes*. If we take any one of the fragments, we find that we can break

it up again easily along planes parallel to these cleavage planes, and by carefully choosing whereabouts to break it we can always get a fragment of the shape shown in Fig. 5.

This is a solid, bounded by six cleavage planes or faces arranged in three parallel pairs, so there are three directions in which cleavage planes run. Each of these faces is a rhombus, and all the rhombuses are of the same shape and size. Such a solid is called a *Rhombohedron*. This rhombohedron is not only bounded by cleavage planes, but other cleavage planes run through it parallel to its faces, for by further taps with the hammer in the proper directions it may be cleaved into a number of smaller rhombohedrons exactly like it in shape. These again can be cleaved into yet smaller rhombohedrons, still of exactly the same shape as the rhombohedron we started with. We might go on doing this, if we could, till the rhombohedrons were too small to be seen even with a powerful microscope; but it does not follow that we could, even in imagination, go on doing it for ever: probably we should at last come to a rhombohedron which could not be broken up by any mechanical means.

The substance we have been speaking of is a crystalline mineral composed of calcium carbonate, and called *calcite*. It is one of the very commonest of minerals, and is easy to know by sight or by easy tests. It can be scratched easily with a knife, but not with the finger-nail; it has an easy cleavage in three directions, as just described, and effervesces with cold acid. When one of the rhombohedrons of calcite is transparent enough, if we put it over a mark made on a piece of paper, and look through the crystal, the mark seems to be doubled. This property is called *double refraction*.

The crystals of calcite show a great variety of shapes.

It is rarely found in the shape of the rhombohedrons, into which it can be cleaved. Its commonest form is called dog-tooth spar, because of its pointed shape. This shape is bounded by twelve or six equal and similar scalene triangles, the longer side alternately right and left; so that the edges which run from left to right go up and down into six or three points downwards, and six or three points upwards, and are not all parallel to one plane like the corresponding edges in the crystal of quartz seen in Fig. 1. Another common variety is called the nail-head spar; it is much more flattened, instead of being sharply pointed, and often has only three faces visible on the upper surface.

Flint and Chert. We often find in limestones lumps of irregular shape, so hard that we cannot scratch them with a knife. When broken they never show any cleavage planes, but break with a very smooth surface, most like a piece of glass. If they are broken by the blow of a hammer, the broken surface will usually show a number of concentric rings round the point where it was struck, something like the ribbings on a shell. This ribbed way of breaking is called *conchoidal* (shell-like) *fracture*. The pieces that split off are often very thin and sharp-edged, so that they cut like a knife, for which purpose they were used in ancient times. These lumps are called *flints*. They are usually dark in colour, but the thin pieces are transparent, and when held up to the light we may usually see some opaque specks in them.

Other lumps, which more often occur in layers and show no conchoidal fracture, but are tougher, more opaque, and show more numerous specks, are called *chert*. If we take either of these kinds of lumps to a chemist, he will tell us that they are both made principally of silica.

LESSON VI

HOW LIMESTONES WERE FORMED

WHEN we see limestones bedded, as nearly all of them are, and lying, as is not uncommon, among beds of sandstone and shale, we may be sure that such limestones were formed under water. Again, many limestones are full of fossils, and the animals of which these fossils are the remnants are such as now live in salt water—shell-fish, coral-polypes, sea-lilies, and other marine creatures; such limestones as these must have been formed under the sea.

We have learned how sandstones and clays have been formed out of the material derived from older rocks by denudation, and finding as we do that limestones are associated with these, it seems not unlikely that the calcium carbonate of which they are chiefly composed may in like manner have been supplied by denudation. But when we come to inquire whether this is so, we soon find out that the formation of many limestones must have differed from that of sandstones and shales in some important particulars.

Some limestones, no doubt, are made up of broken fragments, and may therefore, like sandstones, be called elastic rocks; but when we look at the fragments, we find that they are bits of sea-shells or of the hard parts of other marine animals, and have not come from the land

at all. Other limestones have no trace of clastic structure, but are smooth and even throughout. Again, if we examine the stuff which a river is carrying down, we can see in it grains of sand and particles of mud like those which make up sandstone and shale; but we shall find few if any bits of limestone, except when the river is just running over a bed of limestone.

But though we cannot find any particles of limestone in the mud, we may find the material for it in the water. Let us filter the muddy water and evaporate the clear filtrate to dryness; in many cases, we might say in almost every case, there will remain a material which, on applying the tests we used for limestone, we shall find to contain calcium carbonate, the substance of which limestones are mainly made of.

Here, then, is one great difference. The materials for making sandstones and shales can be seen as they travel down the stream, and they are said to be carried in *suspension*; but the stuff we want for making limestones cannot be seen as it goes down, because it is dissolved in the water, so it is said to be carried down in *solution*.

But still a difficulty presents itself. How can the material be got out of the solution and be made to form a solid limestone? The sand and mud of which sandstones and shales are made, drop of their own weight when they reach the still water; but there is nothing to cause the calcium carbonate to fall down when it gets to the sea, because it is just as much dissolved in the still water as in the running water, and in the salt water as in the fresh water. How then is it got out of the water and made available for the formation of limestone? We may be able to point out several ways, but the following facts seem to indicate at least one likely way.

The hard parts of a large number of marine animals

are mainly made up of calcium carbonate. If the animals did not get it out of the water, where did they get it from? We know of no other source from whence it could have come. On the other hand, there is plenty of calcium carbonate carried down in solution in all the rivers that run into the sea in which these creatures live; and if they only had the power of taking the dissolved calcium carbonate out of the water, they could thus always obtain the material they want for making their shells and other hard substances. That they have this power is rendered certain by the following fact. Though rivers innumerable are day by day carrying into the sea large quantities of dissolved calcium carbonate, yet if we analyze sea-water taken a little way from the rivers' mouths, we find the barest trace of this substance in it. If the inhabitants of the sea have not taken it up, where is it gone to? We cannot find it anywhere except in their hard parts. Thus on one side we find something gone, and we do not know where it is gone to; and on the other we find the same something come, and we do not know where it has come from. What more natural than to suppose that the loss on one side supplies the gain on the other? Thus the calcium carbonate dissolved in the river-water, when that water reaches the sea, is taken up by the animals or plants and used in making their hard parts.

It now begins to dawn on us that the making of many limestones must have gone on in this way. Calcium carbonate is carried into the sea dissolved in river-water. Marine animals or plants take the calcium carbonate out of the water to build up their skeletons or their dwellings, and on the death of these animals their hard parts lie on the bottom, and in the course of time become bound together into limestone.

We become still more convinced when we find that many limestones can be seen to be made up of scarcely anything else but the hard parts of marine creatures. In Derbyshire, for instance, some beds are simply a mash of the broken stems of encrinites or sea-lilies. They make an inferior kind of marble, and are largely used for mantelpieces. In other limestones the remains may not be so obvious. They have been rendered indistinct in many ways. Sometimes water percolates through the crevices, dissolves away a bit of one of the shells in one place, and deposits the dissolved calcium carbonate in some other part of the rock. We find limestones in which this process has gone far enough to make the fossils obscure, but not to efface them altogether; others in which the change has gone to a greater length, and only the faintest trace of a fossil can be detected here and there, till finally we come to those from which every trace of fossils has vanished. So they are all connected together, and we have no difficulty in concluding that a very large number of limestones have been formed in the way described, though we cannot find any fossils in them.

Rocks which are formed in this way by the aid of animals or plants are said to be of *organic* origin, to distinguish them from sandstones and clays, which are said to be *mechanically* formed. We shall learn further on that there is a class of rocks in the formation of which chemical processes play a large part, and these are spoken of as *chemically* formed.

Our next question is, where does the calcium carbonate which travels down dissolved in the river-water come from? If we go to a district where the rock at the surface is limestone, we shall easily find an answer. Hunt out some bare rocky surface, either on a hill-top or

where quarrying operations are being commenced, where the turf has just been stripped off and the underlying rock laid bare. You will be surprised to see how fretted and worn the top of the rock is; running across it in various directions are winding and branching channels, which remind you of the appearance of a large mud flat by the seaside, where the little surface-streams carry off the water as the tide falls; and you cannot help feeling sure that the rugged limestone top must have been made in a similar way by the water that filters down through the turf and streams over the surface of the rock. But though you would not have a moment's hesitation if the limestone were as soft as the mud, you do feel doubtful if such feeble currents could wear away a rock so hard as that you are standing on. You feel sure that the mere mechanical wear and tear of the slowly-trickling water could scarcely grind it away and make such smooth-sided channels.

But recollecting that river-water has been found to hold the calcium carbonate in solution, we begin to think that the limestone may have been dissolved away like a block of salt left standing in water. It may seem unlikely that water can dissolve so solid a substance as limestone, but the experiment made at the end of the last lesson shows that water containing carbonic acid can dissolve calcium carbonate. Now, nearly all water on the earth's surface does contain carbonic acid. Carbon dioxide is present in small quantity in the air, and the rain catches up some as it falls; carbon dioxide is also given off when vegetable and animal matters decay, and the water takes it up as it streams over the ground, so that by the time the water reaches the limestone it has carbonic acid enough in it to enable it to dissolve the calcium carbonate out of the rock. It is in this way

that the network of channels that run in so many directions across the top has been eaten out.

And this process is not confined to the surface. Every here and there we notice round funnel-shaped pits running down vertically deep into the rock; perhaps a little rill tumbles into one of these, and we can hear the water splashing and trickling away underground through a channel that leads we know not where. In the quarry we can see many such passages winding about through the rock, and in some of them the water which entered at the surface is flowing. As the water runs along it is constantly dissolving away the rock and enlarging these tunnels; some of them may be big enough for us to crawl or even walk through, and as we make our way along them we find that every here and there they open out into large chambers. By tracking one of these underground labyrinths we realize how thoroughly the rock is hollowed and honeycombed in every direction, and what an enormous amount must have been dissolved and carried away without any one noticing it, because it went away dissolved in the water. Caverns abound in all limestone districts, and are rare in other rocks. They are simply the great empty spaces left when the rock has for some reason been dissolved away to an unusually large extent.

Various forms of organically-formed Limestones.—Chalk. Chalk is a soft white limestone—often so pure as to contain scarcely anything else than calcium carbonate. If some of the softer varieties be rubbed down with a brush, and the finer particles washed away, the remainder is often seen to contain a number of very minute shells of various shapes and patterns. The same thing may be seen by cutting a very thin slice of some of the harder varieties, so as to be transparent. These shells can

only be seen under a microscope, and they are then found to belong to animals which naturalists class together under the name of *Foraminifera*. They are among the most lowly organized of all creatures, scarcely more than little lumps of live jelly, which throw out long strings of the same substance through little holes (foramina) in the shells. They have the power of taking the dissolved calcium carbonate out of the water and building up out of it the tiny shells in which they live. Foraminifera are doing this now, and many thousand square miles of the ocean-bed are covered by a white chalky deposit



FIG. 6. GLOBIGERINA FROM THE SEA-BOTTOM

called *Globigerina ooze*, largely made up of the shells of the particular kind of foraminifer called *Globigerina* (see Fig. 6). It is to all intents and purposes the stuff which would become chalk if turned into a rock.

In the chalk we often find flints in large numbers, and it seems strange that we should find lumps which are nearly all silica in a rock almost entirely made up of calcium carbonate; and chalk is not the only case of this sort, for nodules or bands of chert are extremely common in other pure limestones.

We can hardly be said to know for certain how these silicious nodules get into the limestones, but we may feel pretty sure that they were not there at the first, for the same kind of flint often fills cracks in the chalk, which were of course formed after the chalk was laid down. The way in which the nodules were formed was probably somewhat as follows.

Besides calcium carbonate, rivers carry down to the sea many other substances dissolved in their waters; of these silica is one. Now, there are other lowly creatures in the sea called *Radiolaria*, which resemble in many respects the foraminifera, but ~~that~~ instead of inhabiting shells of calcium carbonate they inhabit shells of silica, which they get in the same way out of the water. Besides these there are plants still smaller called *Diatoms*, which also build silicious coverings, and in many sponges there are fine silicious needles or spicules. If all or any of these creatures live with the foraminifera a deposit will be formed consisting partly of calcareous (i.e. chalky) and partly of silicious shells. But the two kinds will be mixed together; the silica will not be collected together into lumps. This further step may have been brought about thus:— After the soft ooze has become consolidated, the water finds its way through it, and dissolves out the silica from parts of it, leaving there only calcium carbonate, so these parts become pure limestone; further on in its journey the water leaves behind the silica at some particular spots where we find the lumps, and carries away calcium carbonate instead, so that at these places we get portions that are all silica. Reasons can be given why the water should behave in this apparently changeable way, but they are too difficult for this book.

Coral Limestones. Another class of animals that

have done a large share of the work of making organic limestones are small creatures, commonly called polypes by naturalists, which make the hard things we call corals. Corals include not only the red branching objects which are used for ornaments, but which do not play any great part in building up limestones, but a number of massive white stony specimens with their surface often marked with stars. These are made of calcium carbonate, which the polypes take out of the sea-water. A lump of white coral is often the home not of one polype only, but of many; it is like a town in which each townsman has a dwelling to himself, all the dwellings being the same. If you look at a coral you will see that it is covered over either by rather large stars of various shapes or with little pits or holes; these are the dwellings of the polypes. A town grows by the building of new houses, and so does a mass of coral: in an old town the oldest buildings get broken down, built over, or abandoned; so on a mass of coral new layers are being continually built up on the top of old dead layers, or the coral forms a new branch like a new street. In this way there are formed enormous masses called coral-reefs, covering hundreds of square miles and of unknown thickness: such a reef is formed of calcium carbonate, and is as hard as a stone; it is therefore a kind of limestone.

Among the older rocks of the earth's surface there are limestones of this character, but they are not plentiful. In such a limestone we can see the corals entire and still standing just as they grew, and we may be sure that such coral limestones were originally formed in the sea, for corals never grow on land; and by some means or other, into which we shall have to inquire further on, they have been lifted bodily out of the water so as to form a bed of limestone on the land.

But even modern coral-reefs are not left unaltered when the polypes cease to grow. All along their seaward margin, while the higher parts flourish vigorously in the constantly-renewed water, the lower parts that are dead are beaten upon without ceasing by the waves, and blocks are from time to time torn off, pitched backwards and forwards, broken small, and finally ground down to dust or powder. This broken stuff is spread over the sea-bed around, and in various ways gets hardened into limestone; other parts are thrown over the reefs nearer the land, and we can see what they look like. In this way we can find limestones that are now forming which cannot be distinguished from some of the older limestones of the earth's crust. In both the corals are more or less broken, and may be ground very fine; they lie tossed about in a confused fashion, and none stand as they grew. Mixed with the damaged corals are shells and the hard parts of many other marine animals that kept company with the coral polypes when both were alive.

There is an English limestone, known as the Coral Rag, which furnishes very good instances of both kinds of coral limestone. In some of the quarries near Oxford this rock is coarse and lumpy, and the lumps are old corals standing just as they grew; other more slender kinds have been broken off at the base and lie prostrate, but beyond this they are scarcely damaged; the waves have toppled them over but have not carried them far.

A mile or two away the rock is still rather coarse, and corals are plentiful in it, but they are worn and broken; still further away the rock is fine-grained, but small fragments of coral can be detected in it here and there. Evidently the corals *grew* on the first spot as they grow in a reef, and they are only slightly broken down; shallow water spread round the reef, in which the lumps

detached from it by the waves were rolled about, and by the time the fragments had reached the second spot they were broken up smaller. By the time the material arrived at the third spot it had travelled far enough to be all ground to powder.

There are a good many other special kinds of limestone, almost as many as there are different kinds of animals that make hard parts. Sometimes a number of sea-lilies grow together, and when these break up they make a limestone called crinoidal limestone, such as that already mentioned in Derbyshire. In other cases a large number of various kinds of shells have all been swept together into one spot, and these form a shell-limestone, and many other kinds might be mentioned.

Oolitic Limestones. There is one peculiar kind of limestone very common in England which we see to be quite different from all these. It is made up entirely or partly of very rounded, smooth grains. If these grains are small, a piece of the rock is not unlike the roe of a fish, and so this kind of limestone is called *Oolite* or *roe-stone*. If the grains be larger and flatter they remind us of a number of flattened peas, so the rock is then called a *Pisolite* or *pea-stone*. If these pea-like pieces are pretty large they do not look unlike the pebbles in a conglomerate, but they are totally different in origin; the pebbles have been rubbed smaller and smaller till they came down to their present size, but the pea-like stones appear to have grown larger and larger.

If we break one across we shall find that there is a pattern inside, made of a number of lines running round parallel to the surface, one within the other, till we come to some shapeless fragment in the centre; the same appearance can be seen by the aid of a microscope in the smallest oolitic grain.

It is certain that we have still much to learn about how these grains were made, but something like them can be seen now forming on the beach adjoining a coral-reef, and these seem to be formed somewhat as follows. There may be a grain of sand, a chip off a shell, or a tiny bit of something lying on the beach. It is rolled round and round in the fine calcareous mud, and gets coated with it, or some of the calcium carbonate dissolved in the sea-water is deposited upon it, just in the same way as we have seen it deposited when water containing this in solution is boiled. It then gets a second coat in the same way, then a third, and so on till the oolitic granule is formed. These are then all cemented together by a further deposit of calcium carbonate, and an oolitic limestone is formed.

Where these grains are rather large, either originally or by continued deposition, they seem to be aided in their growth by a curious little worm-like creature of microscopic size, which is known as *Girvanella*. A more careful examination with the microscope of a section of these grains often shows that between the layers there are a number of very fine tubes which curve round in the granule. It looks as if some minute worm-like creature had grown round the outside of the grain and formed a tube there; it was then covered up by the deposit from the water, and another little creature grew round the outside again.

Chemical Limestones. — *Calcareous Tufa.* Where springs come out of limestone countries we often find in the neighbourhood some curious spongy deposits of irregular shape, which are very soft and crumbly. In many cases they contain small pieces of plants, twigs, snail-shells, and occasionally other things. This kind of deposit is called *Calcareous tufa*, and when it is more solid, on

a larger scale, and fit for building with, it is called *Travertin*. Except for the things it encloses, it is entirely made of calcium carbonate in a very loose condition. The spring-water brings this mineral up in solution, and when the water evaporates, or the carbon dioxide in it escapes, the calcareous matter is deposited on anything it comes across, coating it with a layer of limestone. This kind of spring is often called a petrifying spring, but it really only covers the things with stone, and does not change them into stone.

When the water is warm and comes from many springs we may get quite a large deposit formed in this way; and as there are not enough loose things about to get buried in it, it will be very compact. In other cases living water-plants seem to have the power of making the water deposit calcium carbonate all round them, and so build up by degrees a solid mass. All these kinds are forming at the present day, and there are limestones among the rocks of the earth's crust which there is good reason to think were formed in the same way as these calcareous tufas, but they are not very numerous.

Stalactites and Stalagmites. When we get into a limestone cave we sometimes find hanging down from the roof long solid rods which are thick at the top and come to a point at the bottom. These are called *Stalactites*. They are generally wet on the surface, and water is often trickling from their ends. Underneath the spot where the water drops, the floor of the cavern often shows a smooth lump, which gradually slopes down to a level surface. This is called a *Stalagmite*. Sheets of a similar deposit often coat the walls of the cavern and the cracks in the limestone. All these are composed of calcium carbonate, usually in a crystalline, transparent condition. They form so slowly that we cannot easily

watch their growth, but we can find things like them which will show us how they were made.

We may often notice little white rods hanging down in great numbers from the under-side of railway arches. If we go to an arch that is recently built, we find none of these. After a little while, when heavy rain has fallen, the lower edge of each line of mortar will have a drop of water hanging to it; when this dries up the surface of the mortar will not be quite smooth, but have a little bulge—a very little bulge at first—where the water-drop hung. Whenever it rains hard enough you will find the water-drop again hanging to this bulge, and when it dries up the bulge will be a little larger, and so it will continually grow till it is quite a long rod. The whole material of which the rods are made is calcium carbonate, and we can have no doubt that these and the stalactites in caverns were made in the same way. It is this—there is lime in the mortar; the rain which falls on the brickwork contains carbonic acid, which first changes the lime into calcium carbonate and then carries it away in solution. When it comes to the open air the water evaporates, but it leaves behind the calcium carbonate as a little patch on the surface of the brickwork; other drops of water will take the same path and end by hanging down from this patch, each time leaving a little layer on its surface; so the deposit keeps growing as long as there is any lime left in the mortar, and in time a long rod is formed. As these deposits are not always forming, but require that there shall first be wet and then dry weather, each layer will be distinct from the next, and is often discoloured. When, therefore, we cut across a stalactite, we generally find that it is all ringed inside like the stem of a tree, but this we now know is caused by the successive deposits of calcium carbonate.

LESSON VII

ON THE DISTRIBUTION OF THE MATERIAL BROUGHT DOWN BY DENUDATION. HOW WE CAN LEARN WHAT WAS LAND AND SEA LONG YEARS AGO

WE have now seen how denudation furnishes material for making the ordinary derivative rocks, such as sandstones, clays, and limestones. We have followed the débris, while rain has washed it into brooks and while the brooks have swept it into rivers, and the rivers have carried it to the sea. Beyond this we cannot follow it with our eyes, but we know that it must sink down there or be absorbed by living creatures, for it never comes back again. The water which the sun evaporates from the surface of the ocean is perfectly pure, and everything it contained is left behind. In what way will the various materials be distributed, is a question which we must argue out by common-sense, from what we know about substances suspended or dissolved in water, and then we must turn to the descriptions of the different kinds of stuff that have been actually brought up from different parts of the bed of the sea by soundings, and see if they are such as our conclusions would lead us to expect.

A large river in the upper parts of its course where its fall is rapid will often roll along its bed lumps of rock and round them into pebbles, and these get smaller and

smaller as the slope of the river gets less, till in its lower part it can only carry suspended in the water the finer sand and mud, or push small gravel along the bottom. Now we know that when a river has but little slope it will require a more rapid current to carry along the larger pieces, and as the current grows slower these must drop, and only the finer material be carried on.

When the river enters the sea, if its current be strong it may continue to flow for a long distance in the middle of the sea, and carry its mud with it, but in general its motion is soon lost in that of the tides or marine currents. The former case is so exceptional that we may leave it on one side. In the latter case the distribution will depend on the character of the sea. The rivers deliver up their burdens to a new agent, which distributes it in various ways according to circumstances. First let us suppose the sea-water is at rest, or nearly so, and the river is not strong enough to push it aside, then the water of the river will come to rest. The same thing will happen if the river is larger and stronger, and the motion of the sea-water is opposed to it. In this case also the water of the river will be brought to a stand-still. What will happen then? To find this out let us watch the edge of a large puddle during a heavy fall of rain. First, the puddle fills up by the water flowing in in little streams from the ground around it, till there is a pretty large quantity compared with any one of the little streams. You will now soon see that round the entrance of each of these there is formed a little fan-shaped mound, and if you watch closely you will see the grains of sand tumbling one over the other till they reach the edge of this mound, where they will rest and make it larger. This is just what happens on a much

larger scale when a river enters a large lake or a land-locked sea. The fan-shaped mound is in this case called a *Delta*, and the materials that compose it are little else than what the river has brought down. There are no sea-deltas round the English coasts, because the tides are strong and none of the rivers are large enough to make much difference to them, but you may see lake-deltas forming in some of the lakes of the Lake District.

In the greater number of cases, indeed in all the rivers of the British Isles, the burden of muddy material that is brought down is simply given over into the charge of the sea, to distribute according to its own fashion. To know what this is we must go to the sea-side. Suppose we find there a cliff of rock. We shall be pretty sure to find underneath it on the shore a beach of rolled pebbles, some large, some small; some made of the same kind of rock as the cliff, and others which must have been brought from far, pushed along by the waves as they beat on the shore. The banks of shingle will only extend a little way seawards, so they must be wedge-shaped in that direction, but they may extend for miles along the shore.

As the tide goes down we find in many places wide stretches of sand following on the shingle. In places where there are no hard rocks near for pebbles to come from, this sand will reach right up to the land, and seawards it may extend any distance up to three or four miles, according to the slope of the sea-bottom, but this too dies out at last, and is wedge-shaped, but more tapering than the banks of pebbles.

Further out still we may come to mud-flats. Sometimes when the land itself is made of clay, these may come right up to the shore; where there is any sand the mud is only seen at low-water, and if there is much sand

the mud may be only uncovered at dead low-water of spring tides. This is the general rule, though there may be occasionally sandbanks and even pebble banks out at sea, but these are due to exceptional circumstances. How far out these mud-banks extend we can only tell by sounding, but they spread a very long way, and have very little tendency to be wedge-shaped. If you cross the Atlantic Ocean in a steamer, and come into the British Channel, you can see that the water is really muddy all the way across from England to France, and of course the mud will at last sink down to the bottom. Thus it will be spread out in great level sheets of nearly the same thickness throughout.

Of these three materials, pebbles, sand, and clay, the whole of the pebbles will usually be derived from the waste of the cliffs, some of the sand will be obtained by the grinding down of the pebbles, but the rest of the sand and most of the clay will be the contribution of the rivers which flow into the sea ; for, as we have noticed before, much more is brought off the surface of the land than is worn off its edges. The pebbly shingle will lie in long, narrow banks which fringe the shore, and are not affected by rivers, but vary according to the nature of the cliffs ; a little further out are wedge-shaped deposits of coarse sand ; still further out these merge into more regularly bedded layers of fine sand ; and beyond these there will be sheets of mud, evenly bedded and sometimes finely laminated, stretching far away.

When we compare this with the rocks we see inland, there is a wonderful correspondence. Conglomerates, which are nothing more than hardened shingle, are always in the same sort of long thick bands, rapidly dying out in the cross direction. Coarser sands usually follow them, and are irregularly bedded, and these after sundry

alternations, probably dependent on the varying contributions of the rivers and the sea, are usually followed by evenly-bedded clays and shales. We are right then in concluding that these rocks have a similar origin to those we now find forming.

But in all this we have left out of account the calcium carbonate in solution. The reason is that the motion or rest of the water has nothing to do with this. We have seen that limestone is got out of the water by the aid of living creatures. If these creatures are abundant, that is if the conditions are favourable to them, they will make much limestone; but there are but few animals that like to live in muddy water, and if they do the limestone derived from them will be lost sight of in the midst of the sand and clay. It is therefore in places where very little deposit is going on that we can expect to get anything like a pure limestone. There are two kinds of such places—one of these is the open ocean. Even the swiftest river, carrying its mud right through the sea for many miles, will have its current growing weaker and weaker, and at last it will not be able to carry even the finest mud. Here then the last remnants of the farthest-travelled material from the land will sink down, and beyond this line the water will be bright and clear. It is in this clearer water that most of the minuter forms of limestone-forming animals, such as the foraminifera, find their most congenial home, and the sea-bottom beneath it we may expect to be strewn with their hard parts, which in course of time will be bound together into limestone. And it will be pure limestone made up of nothing but calcium carbonate, for no muddy or sandy sediment finds its way out so far.

Another place for the formation of pure limestone is a land-locked sea, when there are few rivers flowing

into it. In this case there is very little mud brought by rivers to be deposited; and the sea itself has not much power to grind down its shores, so there is little sediment, and all that is required is a supply of calcium carbonate in solution, and this by gentle currents, caused by the heat of the sun evaporating the sea-water, may be brought from long distances. In both cases it seems very probable that pure limestone takes a long time to make. A fresh supply of calcium carbonate can only be brought by the movement of the water, and if the water moved fast it would probably bring mud with it, so where nothing is brought but what is in solution, the movement must be very slow.

The conclusions we arrive at from observations near the shore and in the neighbourhood of the land can now be tested by what is known of the material that lies upon different parts of the sea-bed. For such purposes as laying down a telegraph-cable, it is necessary to learn the depth of the sea, and the sounding-lines that are let down to ascertain the depth are furnished with contrivances for bringing up samples of the bottom. Similar soundings have also been made by the *Challenger* and other exploring vessels. From the results thus obtained we learn that on a large scale the deposits now forming on the sea-bed are arranged in just the same way as we have been led to expect from what we see near the shore. Within a few miles of the shores the deposits are comparatively coarse—at 100 miles they are very fine indeed—and as a rule none are found that can have come from the land at a greater distance than 200 miles, except opposite the mouths of great rivers such as the Amazon and the La Plata. In the latter case all the soundings, for a distance of about 600 miles eastward from the mouth, brought up mud and sand which had been worn

off the land and carried out by the river. Further out no such sediment is met with, and the sea-bed is covered with globigerina or radiolarian ooze.

Also if we notice the distribution of the coral-reefs, we shall find that they flourish where circumstances in various ways prevent the access of noticeable quantities of land sediment, as in the Red Sea, the West Indies, and off the coast of Australia.

The relations of limestones to the associated derivative rocks on a pretty large scale is well illustrated in the case of the series of rocks known as the Mountain Limestone. In Derbyshire this consists of a mass of rock, certainly not less than 2,000 ft. thick, which is practically all limestone from top to bottom. Here and there layers of shale lie between the beds of limestone, but they are very few, and then the rest of the rock is very pure. This limestone, then, must have been formed in a part of the sea where mud was very rarely carried, and probably far from the shore. The same rock group extends to Yorkshire and Lancashire with very little change. When, however, we reach Westmoreland, Durham, and Northumberland, we find the group to be greatly changed. It is no longer all limestone; the limestone-beds themselves are mostly impure with clay, and between these beds there are thick masses of shale and sandstone. Evidently as we go northwards we are getting to a part of the sea into which mud and sand were frequently carried in large quantities—in other words, we are travelling towards the shore. In Scotland the same kind of change is carried further, and the group is nearly all shale and sandstone. There are calcareous beds in it, but most of them are so clayey and sandy that they scarcely deserve to be called limestone, and they are so buried amid the prevailing clays and sands that they might easily be

overlooked altogether. Here, then, the supply of sand and mud must have been greater than in the north of England, and we must be still nearer to the coast. Lastly, as we draw near the Grampians, we come upon coarse grits and conglomerates, the materials for which were broken off the rocks of these mountains. It is clear enough, therefore, that a ridge of lofty ground, lying pretty much where the Grampians now stand, formed a northern shore to the sea in which these rocks were laid down.


By tracing the same rock group in other directions we come upon similar changes, and so we can trace round a great part of the margin of the sea in which this particular group was laid down.

All this happens right in the centre of Britain, and we have been tracing the margins of a sea where now there is dry land, so in times past land and sea have changed places. We do not quite know where all this sand and mud came from, but there is not enough land now left to supply it all, if we take away all that was sea at that time. Moreover, the line of shore crosses over into Ireland, and must thus have crossed the present Irish Channel, proving that what is now sea was at that time land.

The illustration we have just given opens up a very wide question. At the time when this Mountain Limestone group was laid down the distribution of land and sea is thus shown to have been very different from the present distribution. But there are many other groups to which the same reasoning will apply, and these groups were deposited one after another, for we may be sure that when we see one group of rocks lying everywhere over another group of rocks, the latter group was formed at an earlier date than the former. For each of these we can in like manner, with more or less

certainly, trace the shore-lines of the seas in which each was laid down, and they are not the same shore-lines as before. And so we come to what is perhaps the most important teaching of Geology, namely, that land and sea have changed places not once only, but many times, and each time there has been new land and new seas in different positions from those of the former land and sea.

How this has been brought about, and what has happened in the interval between the laying down of one group and the next, we shall learn in future lessons; and so we shall be equipped to trace the succession of events which go to make up the long geological history of the changes which have taken place during the building up of the earth's surface.



LESSON VIII

ABOUT ROCK-SALT, DOLOMITE, AND GYPSUM, AND HOW THEY WERE PROBABLY FORMED

THE rocks we have so far dealt with are very common ones, and almost every river and sea will teach us how they were made. But we are now going to talk about some rocks which are much more difficult to deal with, because they are so much more uncommon, and it is seldom that we can see anything like them in process of formation, and in some cases not at all. So we are more or less driven to conjecture. Many of the conjectures that have been made explain so well the facts we learn from observation, that they are in the highest degree probable. We can say that it is extremely likely that this or that one of these rocks was formed in this or that way, but we cannot say that it is certain, or that all of the same kind were formed in the same way.

One peculiarity that all the three rocks we are about to deal with have in common is, that though they occur in masses large enough to be called rocks, they are nevertheless composed of single minerals; in other words they are chemical compounds. As these minerals are new to us, we must procure samples of them and find out their peculiarities; they are called rock-salt, dolomite, and gypsum.

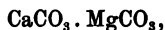
Rock-salt is merely common salt, but it has the name

rock-salt given to it because it is found buried in the earth, to distinguish it from that which is obtained out of sea-water. It has, of course, the taste of salt; it is transparent, usually colourless, but often tinged with red; it can be scratched, but not very easily, with the finger-nail, and it breaks up into cubical pieces, because there are three directions at right angles to each other in which it has good crystalline cleavage. It seldom shows its original crystal shape, but is usually massive. It dissolves in water, and gets wet if left in moist air. Its chemical composition is given by the formula



where Na stands for 23 parts by weight of the metal sodium, and Cl stands for $35\frac{1}{2}$ parts by weight of the gas chlorine. If a piece is put into the flame of a spirit-lamp, it colours the flame an intense yellow, which is due to the presence of sodium.

Dolomite agrees pretty closely with calcium carbonate or calcite, but it differs from it in containing besides calcium carbonate a certain proportion of magnesium carbonate. It consists, in fact, when pure of one equivalent of magnesium carbonate chemically combined with one equivalent of calcium carbonate, so that its chemical formula is



where Mg stands for 24 parts by weight of the metal magnesium. If the equivalents of these elements are inserted and the formula worked out, we find that in 184 parts by weight of dolomite there are $40 + 12 + 3 \times 16 = 100$ parts of calcium carbonate, and $24 + 12 + 3 \times 16 = 84$ parts of magnesium carbonate, or in 100 parts of dolomite about $54\frac{1}{4}$ parts of the calcium compound and $45\frac{3}{4}$ parts of the magnesium compound. A rock which has this

percentage composition is a true dolomite, but it is often mixed with more or less calcium carbonate, in which case the proportion of magnesium carbonate in 100 parts is less than 45 $\frac{1}{4}$. Such rocks are called *Magnesian Limestones*.

The mineral dolomite is shaped in the same rhombohedrons as calcium carbonate, but the faces are often a little curved, and it commonly has a brownish tinge from the presence of a compound of iron as an impurity. The amount of dolomite present in any sample of magnesian limestone can only be ascertained accurately by chemical analysis, but if there is any notable proportion present it can usually be detected by the following simple tests. Put a little chip into a test-tube with dilute hydrochloric acid; if the rock is nearly pure limestone the chip will effervesce at once, but if it is a dolomite, or contains nearly as much magnesium carbonate as a dolomite, it will scarcely effervesce at all, but if we warm the acid by holding the test-tube over a spirit-lamp it will effervesce as briskly as a limestone. Again, boil a piece of dolomite in dilute sulphuric acid till all effervescence ceases, then take the liquid and boil away most of it and set it aside—as it cools you will see little needles of magnesium sulphate, or Epsom-salt, crystallize out of the liquid.

Gypsum when pure is very white; it is sometimes granular, and sometimes looks as if it were made up of very fine silky fibres. In these cases the rock is a collection of small crystals, but the same mineral is found separate in clays, and the crystals are then called *Selenite*, for they have a white reflection from their surface, like moonlight on water. These crystals have one very good cleavage, and by it they may easily be split with a knife into plates not thicker than a sheet of paper, which are

also very brilliant. The surface is so soft that it is easily scratched by the finger-nail.

Gypsum is a compound of calcium, oxygen, and sulphur, with chemically-combined water; it would be called by chemists a hydrated calcium sulphate, and its formula is



where S stands for 32 parts by weight of sulphur. It is the material used for the manufacture of plaster-of-Paris, for which purpose it is heated to drive off the water. This may be easily done on a small scale, and the water made visible. Take a very narrow test-tube and dry it thoroughly by warming it over a spirit-lamp. Take a small piece of gypsum and dry it thoroughly without making it too hot. Now put it in the narrow test-tube, and hold this with the lower end in the flame of a spirit-lamp as nearly horizontal as convenient. Very soon you will see dew form at the other end of the tube where it is cooler, or where it is held by tongs or paper. The heat has driven off the water from the gypsum as vapour, and the vapour has condensed on the cool part of the tube. If all the vapour be driven off, what is left behind in the tube will be plaster-of-Paris.

It is important to know that this mineral is to a notable extent soluble in water. Take two test-tubes and put a little of the same water in each, and in one place a little bit of gypsum; then boil both test-tubes for some time, and when the water is cool again take a drop from each test-tube and place the drops side by side on a glass slip; warm this over the spirit-lamp till the water has evaporated. You will find that the drop that has been heated with the gypsum leaves a much thicker, whiter sediment than the other, showing that it has taken *some* of the gypsum into solution. The other drop may

also show a white sediment, part of which may be the calcium carbonate that the water might contain; and the remainder will be very probably composed of gypsum, which is commonly found in ordinary water.

We must now try to discover the origin of these three rocks, and for that end we must know how they occur in the earth's crust.

Rock-salt, though it is met with in bedded rocks, can hardly be said to be itself in beds. It lies rather in large cakes separated from one another. Each cake is thickest in the centre, and thins away gradually on all sides to nothing. Each cake, in fact, is shaped as if it lay in a saucer of irregular outline. The saucer may be many miles across, and a hundred or more feet deep in the middle, or it may be much smaller and shallower. It is found generally among bedded shales and sandstones, and it almost invariably happens that these are of a deep-red colour.

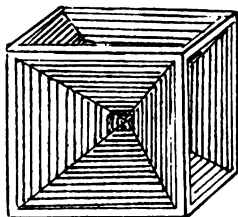


FIG. 7. CRYSTAL OF SALT.

Now let us try an experiment. Take some salt water, put it in an open iron saucer, and leave it out in the air for some days. It will not entirely dry up as ordinary water will, but there will be left a wet cake of salt, and the iron around will be rusted. Now bring the saucer into a warm and dry room, and if it be warm enough and dry enough, the salt will become dry, and will take the form of little hopper-shaped crystals (see Fig. 7), or, it may be, tiny cubes, which will be left as a cake at the bottom of the saucer. At the edges these will be discoloured by the neighbouring rust. Now we have only

to suppose the saucer to be made of clay or sandstone with some iron in it, and to be as large as one of the cakes of rock-salt found in the earth, and then to cover the whole over with some more clay and sandstone, and we get what is actually found in nature, with the shape of the cake and the colour of the enclosing rocks. All we want to start the formation is some salt water, and a dry atmosphere to evaporate the water and leave the salt behind.

Does nature anywhere supply these conditions? We must not expect them everywhere, because rock-salt is a comparatively rare deposit. Of course there is plenty of salt in the sea, but the sea cannot dry up unless a part of it is cut off from the rest, so we must begin by looking elsewhere. Now salt we find everywhere. The air is full of little particles of it floating about; it is present in the soil—we cannot find a place where it is not. So all river-water has some salt in it; the water of some rivers has a good deal. If a river flows into a lake, it carries in salt. If the lake has an outlet, about as much salt goes out at the lower end as comes in at the upper end. But suppose the outlet is in any way dammed up, the lake may rise and overflow; but if this occurs in a country where the heat of the sun makes the atmosphere comparatively dry, the water may be drawn off by evaporation as fast as it is poured in, and the lake keep pretty nearly at the same level all the time. Then we shall have water with some salt in it always going in, and water alone carried away by evaporation, so the lake must get saltier and saltier every year, till at last it can hold no more. Any further salt that is brought in must then be precipitated when the water evaporates, and thus a deposit of salt will be formed in the lake, which will go on forming as long as the conditions remain the same, and finally, if for any cause the

rivers cease to flow into the lake, the whole of the water will dry up and all the salt be left.

And this is no fancy case. It is all going on in the great salt-lake of Utah, and in hundreds of lakes large and small that lie scattered over the western part of Central Asia. We have in such places immense tracts of country from which not a drop of water runs away to the sea ; many of the rivers empty themselves into lakes without any outlet. Such lakes are almost always salt, and the country round where the lake has dried up has in it enough salt to be worth working, and further away salt crystals still lie scattered on the surface. All these districts are very warm and dry, so there are plenty of places where the needful conditions are found.

So far then as the formation of rock-salt is concerned, the explanation that it was formed by precipitation in closed lakes answers well enough. We must now see whether it also applies to the peculiarities of the rocks amongst which the rock-salt lies. First, as already noted, they are usually of a deep-red colour. This red colour is due to the presence, as explained in Lesson III, of ferric oxide. As has been there stated, this usually results from the action of the air on ferrous carbonate. Now ferrous carbonate, like calcium carbonate, can be dissolved in carbonated water, and may very likely therefore be brought down into the lake. Here, as the water evaporates, the oxygen of the air changes the ferrous carbonate, and a red colouring matter will be produced which coats each grain of sand or clay.

Again, the surface of the associated rocks shows some very remarkable features. Here and there the rocks are covered with separate hollows having the peculiar shape of the hopper-like crystals of salt, so that we are sure that salt once crystallized there, which it will only do

when the atmosphere is very dry, and afterwards was gently dissolved away, and the mould filled up with a later deposit of sand or mud. Other surfaces of the beds of red sandstone often show the peculiar markings we are accustomed to at the seaside, which we call *ripple-marks*. These are caused by the ruffling of the very shallow water by the wind, which works up the sand below into the same shape; such marks are only found in shallow water¹. Other surfaces again are cracked in the same way as the mud at the bottom of a pond, which has been dried up during hot weather and cracked by the heat of the sun. On the same surfaces we find also the footprints of animals which waded through the shallow water or walked over the soft mud that had just been laid dry. All these peculiarities are therefore exactly what we should expect under the conditions we have supposed to be those suitable for the formation of rock-salt beds.

Another negative peculiarity must be noticed. In the actual rock-salt of course no fossils can be found, but even in the associated rocks they are extremely rare. They are not, when present, of the easily-recognized marine forms, but consist of reptiles, fishes, plants, and peculiar shells. Now, the modern salt-lakes with which we have compared the basins of rock-salt are certainly not favourable spots for living creatures. They are generally barren, inhospitable wastes, and what creatures are found there are very much of the same general type as those associated with rock-salt. And this is just what we should expect. Very few animals can live in a concentrated solution of any salt; only here and there a spot might be found where the water was less poisonous than

¹ Wind will also blow sand into such shapes, but these could not be preserved. The sand is so loose that the first water would spoil them.

usual—near the mouth of one of the inflowing rivers, for instance—where some creatures of a hardy sort might manage to exist, but there would not be many kinds hardy enough for such a life. The land-plants and bones of land-animals would be swept in by the rivers from the borders of the lake.

All these coincidences seem to show that we have really lit upon the true explanation of some of the beds of rock-salt, at least those found in England. If this be so, we note in passing that the climate at that time must have been much warmer and drier than now: if any one of our beds of rock-salt were exposed to the rain and weather, it is probable they would entirely disappear in the course of a few years.

A great deal that we have said about rock-salt applies also to gypsum, but not all. Like rock-salt, gypsum is soluble in water, but not anything like to the same extent, and a great many rivers contain it in their water; the main condition, therefore, namely the supply of the material, is fulfilled here also, and the same reasoning will apply. We should therefore expect to find beds of gypsum associated with beds of salt, just as we do find them. But the less solubility of gypsum makes a great difference. It is not necessary to dry up the water so far to throw down gypsum as it is to throw down salt. We may expect, therefore, to find places where the drying up went only so far as to throw down the gypsum, while the salt remained in solution and was carried away elsewhere. This accounts for our finding gypsum in many places where there is no rock-salt, but very seldom finding rock-salt where there is no associated gypsum. Nor are such special conditions necessary for the production of gypsum; its presence does not much interfere with animal life, and it is so abundant that

much concentration is unnecessary before it will be thrown down. Moreover, like the flints in chalk, it seems sometimes to have been formed in the rocks after they were hardened and cracked; but this question we must not here follow any further.

Dolomite is altogether much more difficult to account for—indeed it may be doubted if we really know much about it. It differs from rock-salt and gypsum in its mode of occurrence. Though it is often found associated with these, it also occurs in thick beds on a much more extended scale, passing over miles of country. Though fossils are rare in it, when they do occur they are found actually in the rock itself, and not in the associated sandstones and clays. Moreover, they are not of the kind that live in lakes or on land, but are well-known inhabitants of the sea. The number of different kinds or species is not very great, and they are frequently stunted and deformed, as though they lived in unhealthy conditions. When we learn that the water of the sea contains a large proportion of compounds of magnesia, and river-water only a small proportion, the best supposition appears to be that dolomites have been formed in portions of the sea which have been cut off from the rest and converted into a lake. Such a case occurs in the Dead Sea, which has in its water abundance of magnesium compounds.

In some cases dolomite may have been thrown down by chemical means, along with the calcium carbonate extracted by animals from the water. In other cases the limestone may have been an ordinary one, and have been turned into a magnesian limestone afterwards.

LESSON IX

ABOUT COAL AND HOW IT WAS MADE

COAL is found in the earth in beds, amongst other bedded rocks—sandstones, grits, and shales. A series of shales and sandstones, some of them carbonaceous, have been laid down, and every now and then a bed of coal, then more shales and sandstones, then more coal, and so on. The shales and sandstones will have been formed in the same way as others we have been studying, but we must now find out how it was that every now and then a bed of coal was formed instead.

We soon come to the conclusion that coal is made up of parts of dead plants which have been gathered together in layers, have undergone some chemical changes, and have been so strongly pressed together that they have been packed into a hard stony substance. We express this shortly by saying that coal is mineralized vegetable matter.

How we learn that this is the case must now be told. In the first place coal burns like wood, and the gases it produces when burnt are the same as those produced by wood. If coal is analyzed by a chemist he finds in it the same elements as he finds in wood. Coal is not a mechanical mixture, for we cannot separate it into parts by any mechanical means; neither is it a chemical compound, for the proportions in which the elements are combined are not the same in all coals, nor are they

in the proportion of any multiple of the combining numbers of the elements, so that no chemist can give us a formula for coal; and we may say all this in just the same way of wood or other vegetable substance.

Again, in many cases it is easy to see things in coal which look very much as if they had been parts of plants. On breaking a block of coal we often see scattered over the surface patches of a soft smutty stuff which looks something like broken charcoal, and which forms part of the mass of coal. This is called 'Mother of coal,' and when it is carefully examined under a microscope, woody fibres and rows of vessels may be seen like those of certain kinds of living plants. Other coals are compact enough to be cut into very thin slices and so be transparent, and we see remains of plant-structure in these slices.

We may sometimes, too, pick out of our scuttles pieces of coal with curious marks on them like those on some kinds of trees, and in the sandstones and shales amongst which the coals lie we may find the same sort of markings exactly, but in this case they are seen to be on fossils shaped like a tree-stem, and all around are dark marks which we cannot mistake for anything but beautiful ferns. So after all this we cannot possibly doubt that what is now coal was once living trees and other kinds of plants.

But what sort of plants were they? They are not like our oaks and elms, and are much larger than our grasses and weeds, and it takes some searching to find anything now living that reminds us at all of what we see in coal, unless it be the ferns, which are not to be seen in the coals themselves. But when we go into a wild breezy country where there is plenty of moisture, such as may be found amongst our hills, we find some plants called

club-mosses, or in one case stag-horn moss, which is not really a moss, but has strong, rough, straggling branches which sprawl along the ground. It puts up short upright branches with pointed ends, like Fig. 8. There is a narrow central stem, clothed with long, pointed, stiff leaves which lap over each other. From the ends of some of these branches there stands out a swollen spike, in which we find between the leaves little



FIG. 8. A CLUB-MOSS.

capsules or bags, called sporangia. These bags are full of small seed-like things, but they are not exactly seeds, because if you sow them, they produce something which has to go through other stages before it is like the original, so they are called spores.

Now all these things we find reproduced in some of the fossil plants found in the shales, &c., that accompany coal, and some of them even in the coal itself. Sometimes

we find the branches with the leaves on them, only bigger ; but more often the greater part or the whole of the leaves have fallen off. Now, if we pick off the leaves or scales of our club-moss, we find they leave behind the marks or pits where they joined the stem, and these make a kind of pattern. In the stems found with the coals we find large stems with the same kind of patterns, but much larger, and better marked with scale-marks.

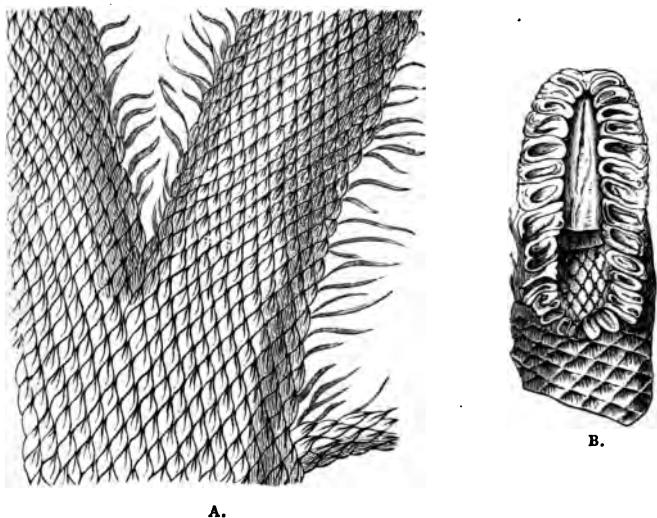


FIG. 9. LEPIDODENDRON (A) AND LEPIDOSTROBUS (B).

These stems have for this reason been called *Lepidodendron*, or scale-tree. Along with these stems, and sometimes, but rarely, seen attached to their branches, are found very large spikes with sporangia at their sides, as in the club-mosses. These spikes are called *Lepidostrobus*, because it was not at first known what tree they belonged to. Fig. 9 A shows a branch of *Lepidodendron* and Fig. 9 B shows a *Lepidostrobus*. The sporangia of the

Lepidostrobus when cut across is found to contain little round grains like spores, and these same spores are also found loose, having escaped from the sporangia; sometimes, but not often, they are quite obvious, and may be picked out with a penknife. In other cases they are very numerous, and all squeezed flat by the weight of the sandstone and shale that has lain above them, and we may have to cut the coal thin enough to make it transparent, when the spores will be seen under the microscope. Coals which, when examined in this way, are found to be rich in spores, are called spore-coals. One great difference between these coal-plants and our modern club-mosses is in size; the club-moss is a small, soft, creeping plant, not rising high out of the ground, though creeping along for a foot or two, but *Lepidodendron* and other common coal-plants are as big as one of our forest trees; nevertheless, it was only an overgrown club-moss.

Another common coal-tree has its trunks fluted lengthways, and in the fluting are marks at different levels like impressions of a seal, from whence the tree is called a *Sigillaria*. From the base of the trunk four great roots spread out and divide many times over into forks, as is the manner of roots. Over the surface of these root-branches are dotted a number of round pits, not very regularly arranged, which has obtained for them the name of *Stigmaria*, before it was known that they belonged to the *Sigillaria*. From each pit a broad black ribbon is given off, which are the rootlets. Fig. 10 (p. 99) shows a *Sigillaria* with its *Stigmaria* attached.

These plants were probably more or less allied to the *Lepidodendron*, but their proper place is not easily made out.

A third great tree was like the so-called Horse-tails or *Equisetums* of our ponds. These also are very large

in comparison with their modern representatives, and are called *Calamites*. Besides these there are many kinds of ferns.

The remains of other kinds of plants are not so easily made out, chiefly because they have so far decayed that no shapes of stems are left for us to judge by, and we can only get bits and examine them under the microscope and see if we can recognize in them any structures that we know in living plants. In this way it is made out that some of the trees must have been something like our fir-trees, or to the cycads of warmer climates. It is this kind that mostly yields the 'Mother-of-coal.' One thing is very curious—all the modern plants which we think are like those found in the coal, either have no true flowers at all, or very peculiar kinds, and are considered to be low kinds of plants. Nothing like oaks or elms or the beautiful flowering trees of more tropical climates is to be found. A coal-forest was not very varied in colour.

But if coal be derived from the wood of long ago, how has it become coal? If we analyze the different kinds of coal, and compare them with the analysis of wood, we soon learn the kind of change in chemical composition that has taken place.

Wood is very nearly one-half carbon, the other half being oxygen, hydrogen, and nitrogen, with a little ash left behind when it is burnt. In some places we can find amongst the bedded rocks pieces of fossil wood, called lignite, and this also occurs in beds like coal, but in different places. It is sometimes called brown coal, and is thought to be generally not so old as the black coal. In this not so much change has taken place, for we can see in it woody fibre, stems, and leaves matted together. But it is harder than wood, and is evidently on its way

to become coal. This contains about 67 per cent. of carbon and a proportionally less amount of the gases that are found united with it in coal. The ordinary coal we burn in our houses contains about 80 per cent. of carbon, and there is another kind of coal called anthracite, in which for some reason or other the change has gone further, so that 95 per cent. of carbon is left. This change has evidently been brought about by the escape of the oxygen, hydrogen, and nitrogen, so that what was left was more and more composed of carbon only—in other words, the percentage of carbon kept growing larger. We find, then, three stages of the change, in lignite first, then ordinary coal, and finally anthracite.

Some coals are more ashy than others. This is because they are not quite pure, but a good clean coal leaving very little ash is practically made up of nothing but these altered and squeezed dead plants. Such clean coals run with very nearly the same thickness over many hundred square miles, and many of them are several feet in thickness. The layer of dead plants before it was pressed down into coal must have been much thicker.

Now this is the problem we have to tackle. In what way can it have come about that a sheet of dead plants, hundreds of miles in area and many feet thick, could have been spread out on the top of layers of mud and sand, which had been previously laid down in water, without any mud or sand to speak of getting mixed with the dead plants?

A fact well known to all workers in coal-mines shows us the way to an answer. Under every one of these clean coals, though not under every seam of coal, there is a bed of rock known as the seat-stone or under-clay, which is quite different in its characters from the shales and sandstones that lie above the coal. It does not

split into layers like shale, but breaks up in irregular lumpy fashion, and looks as if it had been kneaded. Here and there may be seen running through it black streaks which strike down from the top, and others winding and twisting about in all directions. They look very like the rootlets of trees which we see traversing the soil when we dig down into the ground in a wood. It looks very much as if this seat-stone had once been a soil on the surface of the earth, and that trees had grown upon it.

In some cases we can actually see the trees whose roots are passing into the seat-stone. For instance in making one of the cuttings of a railway in Lancashire, there was found in the side something like what is shown in Fig. 10. There was a thin bed of coal with a seat-stone below it and shales and sandstones above it. Standing upright in the coal, and running up through the shales and sandstones above, were the trunks of large trees, and from the base of the trees roots ran down into the seat-stone and spread out horizontally through it. There could be no question but that these trees had grown in the very place where we now find them, when there were no shales and sandstones above the coal, and that the seat-stone had been the soil on which they grew; afterwards they were covered up and buried beneath the shale and sandstone. These trees were the ones noticed above as *Sigillaria*, with their stigmarian roots.

Now we have the key to the problem of the way in which such clean coals were formed, and it must have been in this wise.

We have now in the Fens of Cambridgeshire large tracts of country, very flat, swampy, and lying only just above sea-level. When coal was being formed, a large part of England, still more of Ireland, a bit of

Scotland, and many other countries, were as flat, swampy, and low-lying as our Fens are now. But unlike our Fens

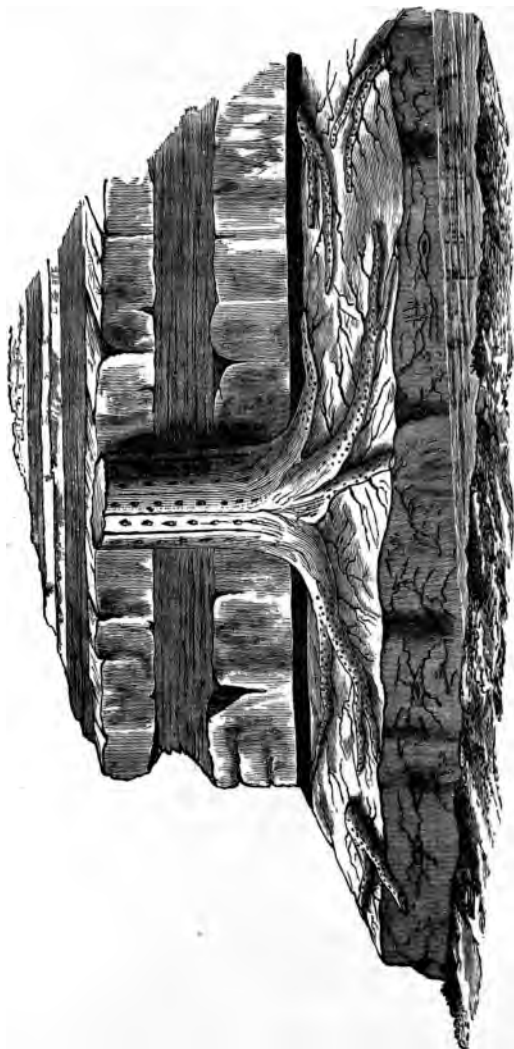


FIG. 10. SIGILLARIA AND STIGMARIA IN POSITION OF GROWTH.

these flats were covered by dense forest and jungle. There were the great *Lepidodendrons*, *Sigillarias*, and *Calamites*, and an abundant undergrowth of many kinds of ferns. But the whole country was not fenland. In many places there was hilly and rugged country. A great mountain mass ran from Norway across what is now the North Sea, through the Highlands of Scotland, and on to the north-west of Ireland. There was mountainous ground in the Lake country and North Wales of a greater elevation than now. All the slopes of these mountains were clothed with forests of trees allied to our pines and cycads.

The trees over the flats died one by one and fell to the ground. Parts of them decayed rapidly, while other parts would not perish so soon. The bark is the most lasting, and remains long after the wood within has gone; the spores are supplied with a resinous substance, which prevents their decay from damp. Remains of these parts would be left recognizable buried in the material into which the rest of the tree had broken up. All this would go on for a very long time, till quite a thickness of dead material would accumulate on the soil in which the first-established trees took root, and it would bury the bottom of their upright stems in the black carbonaceous deposit.

This condition came to an end when the land on which the trees were growing was swamped by a flood, or itself sank, as the land does now and again, beneath the sea-level. In the one case a large lake might be formed, in the other the sea might render the water salt. Into these submerged areas sand and mud were carried by rivers. There the deposits would sink, choke the growth of the trees, and bury the lighter parts of the foliage and break off the more resisting. So we find

in the roofs of the coal-seams many remains of ferns. These deposits become in course of time the shales and sandstones. But yet the water was not filled up with sand and mud, for it still continued sinking, as the deposits were carried into it till the old surfaces on which the trees had grown were buried far out of sight, perhaps some hundreds of feet down, and the remains of the plants were safely sealed up. Thus there were two causes at work—deposition of sediment tending to fill up the water, and sinking of the floor of the basin tending to deepen it. So long as these were fairly balanced sediment of the same kind would continue to fall, but at last the sinking stopped, then the water was soon filled up with mud, and what had been so long submerged became a swampy flat like the flat we started with, and soon became covered with a soil. All this time there had been other parts where the land was not submerged and where the trees still continued to grow, and from thence they soon spread over the flat and covered it anew with forest and jungle. Thus the ground was for a second time overspread by a layer of dead plants, and the whole history as detailed above repeated again and again. In this way coal-seam after coal-seam was formed, each separated from the other by greater or less thicknesses of sandstone and shale, and each having beneath it the soil in which the plants took root.

Such is the history of the clean coals, which possess beneath them a seat-stone or under-clay. But there are many seams of coal which do not possess this seat-stone and are often impure. These cannot have been made in exactly the same way as the others. They are known as drift-coals, and when we understand the history of the clean coals they are easily accounted for. For during all these changes of level of the land there must have

been times when some area of coal growth was invaded by the running water. The decayed material from the plants growing there would be carried on by the water as the lightest form of mud, and be deposited where the sand and clay had previously been left. So we should have a bed of drifted material amongst the shales and sandstones, or in some cases over the surface of the clean coals. One of the most remarkable of these drift-coals is the cannel coal, which never shows any plant-remains of any size : all has been broken up into a fine black substance without any visible structure.

By what slow processes the material which was buried as decayed vegetable matter was gradually turned into the solid and often shining coal, we are not able very well to say. For one thing, we know that there was the weight of all the sandstone and shale pressing it down and squeezing out anything that could be mechanically removed. This would leave the remainder hard. But the gases have also escaped, and we scarcely know in what form. The oxygen may perhaps be found again in water and carbon dioxide, and some of the carbon and some of the hydrogen may have escaped together in the form of the paraffin which saturates the shales in some places where coal is also found. All we do know is that the process takes a very long time, for in most of the newer coals of the world it has not yet been completed, or even brought to the stage of our ordinary household coal.

LESSON X

ABOUT GLACIERS AND ICE-SHEETS, AND HOW WE
LEARN THAT THERE WERE ONCE GLACIERS
AND ICE-SHEETS IN COUNTRIES WHERE THERE
IS NOW NOTHING OF THE KIND

IF you go to the top of a high hill, you always find it cold; even if it is the middle of summer, if the hill is high enough, the whole ground is covered with snow and ice. This seems strange, for the same sun is shedding his warmth on you at the top as at the bottom of the mountain. Why then is one part so much colder than the other?

We get a hint as to the reason when we notice that so long as we stand in the sun we do not feel the cold of the mountain top; but though we are surrounded by snow and ice, the heat of the sun is more than we can bear—our shady side may be quite cold, but on the other side the sun may be scorching our face; when we step out of the sun into the shade we feel the bitter cold. At the bottom of the mountain, though it is warmer in the sun than in the shade, it does not make so much difference—we feel warmed all round.

The fact is we are constantly losing heat, and if there is nothing to supply the loss we feel cold. Now the air at the top of the mountain has not heat enough in it to warm us, but the air in the low ground has much more,

particularly if it is moist. And there is a reason for this. The air is not a particularly good holder of heat, and where there is very little air it cannot hold much. Now, at the bottom of a mountain the air is much thicker than at the top, for the air is easily squeezed, and that at the bottom has all the air above it to squeeze it down, but that at the top has much less, so the air at the bottom can hold much more heat, and this makes all the difference. In both cases the greater part of the sun's heat passes right through the air and heats the ground, and the ground in turn heats the air, for it is much more easily heated by touching something hot than by hot rays passing through it. At the bottom of the mountain the air is dense enough to hold much heat, but at the top there is so little air that the heat of the mountain cannot be kept in; it escapes, and the mountain gets cold enough to let snow lie there, and as soon as this happens half the heat is reflected away from the white surface, and the rest is used in melting the snow and letting the water run away, and none is left to warm the air.

And so it comes to pass that all over the earth, however hot it may be under the air, if there are mountains high enough we reach sooner or later a level where the temperature of the air at its hottest is never above the freezing-point, and whatever falls from the clouds comes down to the ground in the form of snow. In every country, then, there will be a line on the mountain-side, if the mountains are high enough, above which the snow will lie all the year round. This is called the *snow-line*, or *limit of perpetual snow*. Its height depends upon many things, but mostly of course on the sun's heating power; so it is very high in the centre of Africa at Mount Kenia, some 20,000 ft.; in the Himalayas it drops to 16,000–18,000; in the Alps to 6,000–8,000; in Norway

to 1,000–4,000 ft., and comes down to about sea-level in Spitzbergen.

On the land, then, above the snow-line, snow keeps perpetually falling; some perhaps is evaporated again by the sun, but none runs away, as would happen if it were rain, so the snow gets spread layer over layer till a mighty cake of snow is heaped up. The lower part of this snow begins to be pressed down by the weight of the snow above it, till it gets turned into ice. Some ice is nothing more than squeezed snow. You can make a snowball almost as hard as ice by squeezing it with your hands, and by using a press you may actually turn it into a ball of ice. This stuff on the mountain tops, half snow, half ice, is called by the French *névé*, and by this term we usually speak of it in England. The area on which it lies is called the snow-field or gathering ground.

We have a notion that ice is brittle, and so it is when it is treated in certain ways; if you hit it with a stick or hammer it will break like glass. But if ice be treated in the proper way, it can be bent like wire, or moulded into any shape like clay or putty. And the way to make it behave thus is not to hammer it, but to press it gently at first and then with increasing pressure. In the experiment we tried before to show the expanding power of freezing water: if we leave the hole in the iron shell, by which we have filled it with water, open, when it freezes the ice will no longer burst the shell, but will be squeezed out through the hole by the pressure of the ice forming behind it.

Now this is just the sort of thing that happens in the snow-fields. Here a great sheet of ice and snow has been heaped up till it is many hundred feet thick and the lower layers are very much pressed; they are accordingly squeezed out down the slopes of the country,

and particularly down the upland valleys. When once in the valley, more gets squeezed out behind it, and it keeps slipping or moving lower and lower till it reaches ground where it melts as fast as it moves down, and there of course it ends. This squeezed-out piece of moving ice is called a *glacier*. It has never yet been quite explained how the glacier manages to get so far down as it does, but it is certainly always moving, summer and winter alike, very much as a river moves, only much more slowly—a foot or so a day, less or more.

In cold, northern regions, where the snow-line lies low, it sometimes happens that all the high ground in the country is above its level. This is the case in Greenland. The interior of that country is a plateau well above the snow-line, and snow has been gathering on it we know not how long, so the thickness must be very great. The ice that is squeezed out from the edges of such a snow-field is enough to cover nearly the whole of the sloping ground that leads down from it to the sea. So here nearly all the country, high and low alike, is buried in ice and snow, and this great covering is called an *ice-sheet*.

When such an ice-sheet or glacier comes down to the sea, the water will tend to float the ice, and even if this be pushed below sea-level, pieces will at last break off, and these float away as *icebergs*.

The phenomena of ice in these various forms are of interest to the geologist, because they help him to explain things which are otherwise unaccountable, and to tell him something of the history of the earth which he otherwise would not have suspected. If you live in the neighbourhood of glaciers, and see them advance one year farther into the valley and another year retreat, it is not difficult to believe that they once were bigger

than now and extended farther than now, and when you ask how much farther they extended the answer can only be found by seeking for the marks they leave behind them. But who would suppose that the smiling Pass of Llanberis was ever occupied by a glacier, or that the Highlands of Scotland were covered, like Greenland, with an ice-sheet? Yet they have left their marks behind them, though we in England never recognized them till some one who lived among the glaciers of Switzerland came here and knew them at once. We have now, then, to learn what these marks are.

If you go into one of the narrow Devonshire lanes you will find the roadway in places passes over solid rock, and into this rock you find a pair of deep ruts have been cut. Though there are no carts in the lane at the time, yet you happen to be sufficiently familiar with cart-ruts to feel sure that these have been made by carts constantly travelling over the bare rock. If you go to the now uncovered city of Pompeii, buried 1,800 years ago by the dust from Vesuvius, or if you get a photograph of the streets, you may see deep ruts there also. Certainly no carts have gone over those streets for 1,800 years, yet you know full well that many a heavy-laden Roman cart must have passed along the thoroughfare before such deep ruts could have been cut in such solid rock as that they are paved with.

Just so is it in the case of ice; when you see grooves cut on solid rocks along the course of a valley, you ask what can have carved them out? They are not plough-marks, nor can stones in rivers make such marks, and if you know nothing about glaciers your question will remain unanswered. But if you go to where glaciers are now, you will find just the same sort of marks, where the end of the glacier has melted away

and the rock over which it has travelled is laid bare. And this is the way in which they are able to cut these grooves. As they pass along the mountain valley, blocks of stone and smaller pieces of rock keep tumbling off the sides of the mountain and roll down on to the top of the glacier. Some of them fall through the cracks in the ice and get to the bottom, and there get frozen into the ice. So the underside of a glacier becomes so thickly studded with hard, pointed stones that it is like a great rasp, and the sharp sand into which the rocks are ground coats it over till it becomes like a sheet of emery paper. The weight of the ice above presses the stones and sand firmly against the rock underneath ; as they are dragged along they grind and wear it away. Anything that sticks up is gradually shaved off till the surface becomes rounded, smoothed, and polished. The small stones scratch, and the big stones cut ruts or grooves in the smooth surface. In Fig. 11 we have a surface that has been polished and scratched in this way. As we now know that it is ice that does this work, we call such surfaces *glaciated* surfaces.

These are the things that are seen in Switzerland when the surface off which a glacier has melted is exposed, and there is such a special look about it that one who has seen it a few times cannot possibly mistake it for markings on rocks made in any other way. So if we find this special kind of marking anywhere on a rock-surface, we may be sure that a great mass of ice with stones imbedded in it has once moved over the ground. These traces of ice-work have been recognized in many parts of the world which now have no glaciers at all. Glaciated rocks are seen at high elevations in the Highlands of Scotland, in the mountains of Ireland, Wales, and the Lake District, very abundantly in Norway

and Sweden and certain parts of North America. And we learn a good deal about the ice itself from these scratches, for of course they run in the direction in which the ice was moving, though we cannot always make out at which end of the scratch it was begun. The story told by these scratches is often a very wonderful one.



FIG. 11. A GLACIATED ROCK-SURFACE.

But there are other marks of ice besides the scratches, though not quite so certain. When you look at the sides of the valleys where a glacier is moving, you find oval hillocks of a peculiar rounded shape, generally steeper on the side facing down the valley, and more gradually sloping on the upper side. The surface is here and on the top quite smooth and slippery, and usually has the scratches above described. Where the glacier has melted and we see a number of these hillocks, or

hummocks of rock, bare and light coloured, standing up in the more grassy surroundings, they look at a long distance like a flock of sheep, so the Swiss have called them *roches moutonnées*, and we have adopted the term. Now if we go to any of the countries mentioned above—say, to the Highlands or to Wales—and look at the lower parts of the ground from a distance, you will see the same rounded hummocks as those of Switzerland. When you come to walk over them, you see how frost and the weather are breaking up and destroying their smoothness; they are oval, steepest on the side away from the mountains, and on some at least you will find the



FIG. 12. *ROCHES MOUTONNÉES.*

polishing and scratching characteristic of ice (see Fig. 12). These 'roches moutonnées,' then, are another proof of the former presence of ice.

It is not uncommon to find that these marks are confined to the low ground, and that they suddenly cease as we climb above a certain level. This must be the level to which the ice reached, or only a little below it. If the marks are found only in the valleys, we know that the ice was only abundant enough to produce glaciers. If, on the other hand, they go right over the summits of the hills, as in some parts of the Highlands, the whole country must have been wrapped in a great ice-sheet.

Again, there are further and quite different signs that ice leaves behind it of its former presence. If in our Devonshire lane we found the way blocked by heaps of potatoes or turnips, we should conclude that carts laden with these vegetables had come along the lane and been upset at the spot. Something of the same kind happens with a glacier. As it passes along, blocks of rock, stones, and dirt roll on to it from the rocky sides of the valley, and its surface near the edges gets covered with rubbish. This heap of rubbish is carried forward as the ice slips along, rubbed down a bit, and finally dropped when the glacier reaches its end. Here all the heaps of rubbish brought down by the glacier and its tributaries are mixed pell-mell together and piled up in front of the glacier, making what is called a *terminal moraine*. If the glacier grows bigger it has to push this in front of it or climb over it; if it grows smaller it leaves a trail of stones above the moraine. The side-heaps of stone and rubbish on the glacier itself are called *lateral moraines*: if the glacier melts, these are left behind to mark the limit of the glacier in the valley it once occupied.

Moraines of both these kinds are found in valleys where ice-scratches show there were once glaciers; and when we cannot find these scratches because they have been destroyed or covered by the soil, or the rocks were not hard enough to take them, we may still find proof in these moraines of the former presence of the glacier by which they have been left. We may learn also from them the extent of the ice, for the highest lateral moraine will tell us how far up the side of the valley it once extended, and the terminal moraine will tell us how far out it reached into the plain. We do not know so much about the moraines of an ice-sheet, but it is probable that it will have a terminal moraine to mark

its boundary. It is thought that such a boundary may be traced across England of an ice-sheet which once covered the north of Britain.

Besides these marks of the former presence of ice, which every one must agree to, because we can match them amongst the glaciers now in existence, there are other phenomena, which are obviously very similar to those of moraines of the lateral and terminal kind, but which extend far away beyond any places where we can find the scratching or the 'roches moutonnées,' and are on a much larger scale than the recognizable moraines. These phenomena are very interesting, and yield an almost inexhaustible storehouse of curious facts, but there are many opinions about them.

Going back to our glacier, we know that some of the stones that fall on it are let down through the cracks into the bottom of the ice, where they do their graving and polishing work. What becomes of the old tools and of the scrapings of the rock they have worked upon? While the glacier is there they will be carried on and mixed with the terminal moraine, but when it melts away it will all be left, stones and clay together, on the floor of the valley where the glacier was, like the heaps of dust and dirt which are left on the ground when dirty snow has melted. This sort of stuff has been called a *bottom moraine*, or in French a *moraine profonde*. Whether such stuff can be expected at the bottom of an ice-sheet we cannot be very sure, but there is in many parts of Scotland a surface-deposit of stony clay, called *till*, which is thought to have been originally a bottom moraine, but it is so widespread it would require an ice-sheet to produce it.

Lastly, the icebergs which break off from the Greenland ice-sheet bear on their backs the blocks of stone, &c.,

which have fallen on the surface of the ice-sheet. When they float away they carry their burden with them and leave it where they melt, which may be at the bottom of the sea, or on a rock where they have stranded, but in most cases many miles away from the place from whence they started. If the ice-sheet was very large, the stones that fell on it would be carried to its borders, and when the ice melted might be left many miles away from the place where they first fell on to it; or the ice-sheet in its early stages might push the rubbish lying in its path in front of it as it was being forced out, so that there are several ways in which ice might remove a very large stone from one place to another.

We find scattered about in various places great blocks of rock which do not belong to the district, and can only be matched many miles away, and they are generally odd-shaped, as if they had not been rolled much. They are called *erratics*, or *travelled stones*. When we see them and can find out where they came from, we can safely conclude that ice in some form has performed the journey and brought them with it; but which way exactly they came, or what was the form of ice that bore them, are questions to which different people give different answers. Some even think, when they find travelled stones in this country that they can only match in Norway, that the whole of the North Sea was once covered by ice. Most of the places where these stones are deposited are like museums, from the number of different varieties of rock that are gathered together there.

LESSON XI

ABOUT CRYSTALS

BEFORE we can understand what a crystal really is, we must have some knowledge of the physical properties of different kinds of things. The account we have to give of these matters is *theoretical*, because we cannot actually see the things which we talk about, but the theory is founded on what we do see, and is the only way we know of that will account for it.

We have seen that each element has its own atomic weight, that is to say, for instance, that whether oxygen unites with silicon to form quartz, or with hydrogen to form water, or with iron to form ferric oxide, if we want to make the formula for these compounds, so as to indicate how much of each ingredient is taken, we must always reckon O at 16. In the same way we must always take silicon as 28. Now, as far as the proportion goes between these two, we might just as well write 8 and 14 or 4 and 7; but if we take the smallest atomic weight known, viz. that of hydrogen, as 1, then O must be taken as 16 times as great. This seems to show that the numbers 16 and 28 represent something peculiar to oxygen and silicon respectively, and we suppose this to be because the element we call oxygen in quartz is made up of an enormous number of extraordinarily minute things which are all alike, and each of a definite weight, and nothing we can do chemically or otherwise can break up one of these

things ; each, therefore, is called an atom. And we suppose that the smallest possible piece of quartz is made up of one single atom of silicon, and of two atoms of oxygen. We may take a piece of quartz and pound it into the finest dust, but still the finest particle in this dust will contain a very large number of atoms of silicon, and always twice as many atoms of oxygen. But though we cannot get so small a thing—and if we did, it would be too small to see even with the highest power of any possible microscope—we may *think* of a piece of quartz in which there should be one atom of silicon and two of oxygen, and this minute, almost infinitesimal, piece we call its *molecule*. Theoretically, then, we can divide up quartz by mechanical means into separate molecules, but to break up a molecule we require chemical means. What is true of quartz is true of all substances. They all consist of molecules, and we define a molecule to be the smallest particle of a substance which can exist without losing the properties of that substance.

We know something about the relative weights of these molecules ; for instance, we must always reckon the molecule of silica as 60, while the molecule of water is 18, and so on, but we know nothing about their size and shape, and how they are packed together in different substances. But in the same substance the molecules are all of the same size and shape, so when we find a substance like water taking different states, viz. a solid, a liquid, and a gas, we conclude that the molecules are sometimes close together and sometimes far apart, so that they must be able to move. It is, in fact, believed that they are always moving. With this, however, as geologists we have very little to do, but only to note that in a solid the molecules are not believed to be able to do much more than turn round, that is to say, they

can arrange themselves under certain conditions while the body remains solid all the time, and they appear to have a tendency to do so, particularly when the substance is squeezed. Just as in a crowd, when it begins to form, people are turning different ways, but as soon as the pressure comes on they all turn and face the same way.

We are now in a position to explain what we mean by a crystalline substance. We can easily understand that the physical properties of a solid body will depend very much on the way in which its molecules are arranged; and, as we shall see, there is good reason for thinking that in a glassy or non-crystalline solid, there is nothing orderly in the arrangement of the molecules, which are scattered about like people in a crowd, but in a crystalline body the molecules are grouped in an orderly fashion, like soldiers drawn up in rank and file.

There are two properties of crystalline bodies that are very easily illustrated by means of the above, or similar comparisons. If you take a load of bricks and simply tip them into the road, they will occupy more space there than when arranged in the cart. It is known to be so, and must be so, because in the cart no spaces are left between the bricks, but when they lie anyhow there are plenty. We may conclude, then, that the molecules in a crystalline body are likely to be more closely packed than in the same body when in a non-crystalline condition. This is generally the case. Bulk for bulk, the crystalline form of a substance weighs heavier than its non-crystalline form, i.e. its specific gravity (see p. 23) is greater. But this is not always the case, because the arrangement of the molecules in the crystal may be like what is called 'open order.'

Again, if the things are arranged in order you can usually find some easy path through the middle, as an

officer might pass between the ranks and between the files of a regiment, but there is no pathway through a crowd. Just in the same way there are found directions of cleavage in a crystal, but not in a non-crystalline body.

With regard to the formation of crystalline and non-crystalline substances, there are two things especially to notice. First, that the arrangement of the molecules takes time. If the circumstances are such that solidification is sudden, the molecules will have no time to step into their places, but if they have time they will take up their proper position; so as a rule slow solidification is more likely to produce crystalline arrangement of the molecules than rapid consolidation. Secondly, that an orderly arrangement is more likely to be permanent. If the particles (or people) obey no rule, they are very likely to change their position, but when they have become orderly, the same reasons which made them take up that position will probably make them keep it. In a glass the molecules may be said to be in a constant state of protest against the disorder that prevails among them, and to be incessantly struggling to range themselves in crystalline ranks; and give them the smallest freedom of motion, they will carry their point. A glass may in course of time become crystalline, but a crystal, unless melted and cooled, will never become a glass.

There are some beautiful illustrations of these two laws of the formation of crystalline bodies which we must describe. The result of fast or slow cooling is well seen in the dross or slag that flows out of a blast-furnace during the smelting of iron ore. It is frequently run into iron vessels, and the blocks are broken up for mending roads. A bit of this hardened slag taken from the outer part of the block may be easily obtained. On

the outside is a layer of what any one would call glass, but the inner part is stony. If a thin slice of this be cut so as to show both the glassy crust and the stony interior, and be examined under a microscope, no crystals will be seen in the glassy crust, nor will any light pass through when 'crossed nicols' are used. This is the part that touched the cold side of the iron vessel, and consequently cooled rapidly; it has, as we saw reason to expect, turned into a non-crystalline solid. Its molecules became fixed before they had time to group themselves in crystalline ranks. But as we get near the edge of the stony part, we notice scattered through the glass small bodies which are star-shaped or branched and mossy in form, which are bright with the crossed nicols, and which we therefore judge to be crystalline. These crystalline bodies grow more and more numerous as we draw near the stony part, till very little else can be seen. Here we have a part which cooled more slowly than the outside of the block, and here accordingly the molecules began to find it possible to range themselves in orderly rows before they became fixed down, and so they formed crystalline clusters. And these crystalline portions grow more numerous the further we get away from the outside, because the nearer the centre we are the slower will be the rate of cooling. In this case the mass cooled everywhere too fast to allow anything like large crystals forming; but if care be taken to cool the slag very slowly indeed, it becomes more coarsely crystalline.

The tendency of a glassy substance to become crystalline as it gets opportunity is also illustrated by artificially-formed glass. If a bit of clear glass be kept for some time hot enough to soften but not hot enough to melt it, and then be allowed to cool very gradually, it turns into a white opaque substance like china, which is seen under

the microscope to consist of minute crystals. A like change often takes place without the aid of heat if only time enough be allowed. Glass bottles that have been lying for centuries in Egyptian and Etruscan tombs, when dug up and examined are found to have become opaque and stony on the outside, and this stony crust is crystalline. It is said to be devitrified, and the process is called devitrification.

We have dealt so far with the interior substance of a body which is such that we call it crystalline. But it is easy to see that when not interfered with by the boundary in which the substance is enclosed, this orderly arrangement of the molecules in the inside tends to produce a corresponding regularity in the external shape. A *crystal*, therefore, is a body which has a regular, or rather a definite, geometrical shape, which is due to its crystalline structure. All crystals must have a crystalline structure, but all bodies with crystalline structure need not have the external form of a crystal. Such bodies as are crystalline, but have not a crystal form, are called *amorphous*. In this case they probably would take a crystal form if they could, but so many parts try to become crystals at the same time, that they interfere with each other, and a crowd of small crystalline patches is the result; or, on the other hand, they may only differ from a single crystal in the fact that they fill up a cavity and take its form instead of their own proper form.

The forms of different crystals may depend to some extent, for all we know, on the shape of the individual molecules, but for the most part it is brought about by the way in which they are arranged, such as a regiment may be drawn up in ranks or columns, in squares or in diamond shape; and each substance has only one group of forms in which it can crystallize, all related to each

other by certain laws. These laws form the subject of the science of crystallography, which we will not here pursue further than to say that these forms are classed together in six distinct systems. The only one of these we need here mention is that derived from the cube. In these crystals the arrangement of the molecules is pretty much the same in every direction, but in all the other kinds there are certain directions in which the arrangement is different to others, at all events as regards light.

We cannot in this elementary book go into the reasons why most crystals appear bright when seen under 'polarized light' between 'crossed nicols.' We can only say that all of them under these circumstances appear dark when placed in certain particular positions, and that crystals related to the cube appear as dark as glass does, in whatever position they are placed, and we must remember this when we examine their thin sections. We may, however, get a dim idea of the reasons in this way. Polarized light is orderly light, and between crossed nicols this order is such that no light can get through. When glass is examined it is not orderly, and does not interfere with this order in the light; nor do cubical crystals interfere with the order, but other crystals do interfere with the order, and change it to another order so that light is able to get through. This circumstance, when understood, may be taken as a proof that the arrangement of molecules in crystals is an orderly one.

We will now describe a few of the minerals that we shall have to deal with in the next chapters, which commonly occur in a crystalline condition.

Quartz we are already acquainted with. It is very common in a certain group of crystalline rocks, but we do not see it there in crystals of any shape, so we have to

recognize it in other ways. As seen in the rocks it is a transparent mineral, usually colourless, but occasionally with a rosy tint. It breaks in an irregular way, so the surfaces are irregular; but as the fractures are very smooth, it shines when the light is reflected from it, but always in an irregular way. It is, as we know, so hard that we cannot scratch it with a knife. These characters will usually enable us to detect quartz in a rock when the pieces are large enough to see. When seen in thin section with polarized light, quartz gives a very uniform tint and shows no lines of cleavage. We remember that the composition of quartz is pure silica.

Felspars. Of these there are many kinds, and we have only spoken of potash felspar. Whatever the kind of felspar in a rock, it has certain characters by which we can usually tell it. It may be more or less opaque and pink, or it may be almost transparent, and look as if there was some blue about it, but it is seldom green or a good brown. Also the crystals break most easily along the cleavage planes, so that one of these usually forms the surface that one sees. It does not shine very brilliantly, and often looks as if there were flakes half split off, but it is very different from the uneven surface of a broken bit of quartz. It is also not so hard as quartz, and we can manage to scratch it with a good knife. The different kinds depend upon whether one of the ingredients is potash or soda or lime, the others being always silica and alumina, so we speak of a potash felspar, a lime felspar, a soda felspar, or a soda-lime felspar. The potash felspars are straight-splitting, i.e. the two cleavages are at right angles, and these are called *orthoclase* felspars in consequence. The pink, white, and opaque ones are mostly of this kind. When seen in polarized light they often look dusty, and are sometimes of different tints in

the two halves. The others felspars are oblique-splitting, i.e. the two cleavages are not quite at right angles, and these are called *plagioclase* felspars. They may be an opaque white, or nearly transparent, with a blue sheen according to the variety, and they generally show a large number of thin bands separated by lines, and these bands when seen in polarized light are of different tints.

Micas. These we have also noted before. Though there are several kinds they can all be recognized in a rock, when they are large enough to test, by their brilliant shining surfaces. They are brighter even than the smooth fractured quartz, and they differ entirely from that by having the surfaces quite flat, so that the whole of the mineral shines at once when the light is in the proper direction. For another thing, they are soft enough to be scratched by the nail. The shining surfaces are cleavage surfaces, and these lie close together one under the other, so that it is easy to spring off a flake of the mineral with the point of a knife, and if we bend the flake we find it is elastic and flies back when let go. In thin sections we see in most a number of parallel lines, which are the edges of the cleavage planes, and when we have only the bottom nicol on, the crystal changes colour as we turn it round. Minerals which do this are called *dichroic*. All micas have a very complex composition, the ingredients being silica, alumina, potash, magnesia, iron, and other substances, not in the same proportions as in a felspar. There are two principal kinds. One of these is a *potash mica*, that is, there is more of potash in it than in others; it is white, and is called *muscovite*. The other is a *ferro-magnesian mica*, that is, its most important characteristic ingredients are iron and magnesia; it is black and is called *biotite*.

Most of the above minerals, except the biotite, are

usually light in colour, i.e. they are grey, pink, or white. They contain a large proportion of silica in their composition, and such minerals or rocks as contain much of this are called *acid*. The other minerals we have to speak of are a great contrast to these. They are highly coloured, mostly green, and do not contain so much silica, consequently the third ingredient, magnesia, lime, or iron, is more important, and hence the minerals or rocks are called *basic*.

Augite. This is found in dark-looking rocks, and is itself dark, so that any transparency cannot be easily noticed. It is a brilliant mineral, usually brownish or greenish, and in rather short, square-looking prism (see Fig. 14, p. 127). It is not quite so hard as felspar. The surfaces are usually irregular, but we may see on them two sets of cleavages crossing nearly at right angles. In thin sections with polarized light it gives brilliant colours, but does not behave like mica, that is, it is not dichroic. Augite is a compound of silica, magnesia, and iron, and contains little or no alumina.

Hornblende is very nearly allied to augite—in fact we cannot distinguish the composition of one from that of the other in any clear manner, but their physical properties are different. Hornblende is more often a dark green, almost a black. It is much tougher than augite, so tough as to be compared to horn; its crystals are not so brilliant, in fact they are rather dull, and often appear to be fibrous, and they have a different shape (see Fig. 22, p. 152). When broken across we see the cleavage cracks making an obtuse angle with one another. In polarized light it behaves like mica, that is, it is dichroic.

Olivine. As seen in rocks, it occurs in small irregular pieces without definite shape, and looks very like quartz in its fracture, but it is of an olive-green or dark green

colour, which quartz never is. It is not quite so hard as quartz, and when cut in thin slices it gives very vivid colours in polarized light. It is a compound of silica, magnesia, and iron. Olivine is very liable to decomposition. It is full of cracks, and these let water act on the mineral and combine with part of it, by which means they are filled with a fibrous substance called *serpentine*, which is soft and mottled and itself decays into soapstone or tailor's chalk, just as potash felspar decays to kaolin. These altered parts in time spread all over the mineral, and a massive serpentine rock is the result.

Magnetite. This occurs as black grains, which are quite opaque. Sometimes they look triangular, at other times square, according to the way in which they are broken. They consist of magnetic oxide of iron or lodestone, and consequently when they are abundant in a rock it will affect the compass-needle.

The greater number of all common crystalline rocks, that is, of rocks containing or made up of crystals, are really mixtures of two or more of the above-named nine minerals. If the minerals quartz, orthoclase felspar, and either biotite or muscovite, predominate, the rock will be an acid one; if the other five predominate, it will be a basic rock.

LESSON XII

ABOUT CRYSTALLINE, GLASSY, AND FRAGMENTARY ROCKS

THERE are some rocks which are either entirely or very largely made up of crystals or crystallized minerals, and by far the larger part of these minerals are the silicates described at the end of the last lesson. Such rocks are often put together into a large class and called crystalline rocks. It is seldom that we meet with perfect crystals in these rocks. The minerals may be partly bounded by crystal faces, and partly irregular in outline, or they may not show any crystal faces at all.

Sometimes the whole rock is built up of crystalline minerals, often large enough to be distinguished by the eye, locking into one another. Such a rock is said to be largely or coarsely crystalline ; and, because all its constituents are in a crystalline state, *holocrystalline*. In other cases the rock is so closely grained and compact, that we should never suspect that it was crystalline, but the microscope shows us that it is composed of an interlacing mass of very small crystals or crystalline grains. Such a rock may be holocrystalline, but because its crystalline texture is not obvious to the unaided eye, it is called *cryptocrystalline*.

In other cases again we can distinguish large crystals set in a base, or matrix as it is called, which may be

cryptocrystalline, or even glassy. Such rocks are called *porphyritic*.

Or we may find a rock which to all appearance is glassy, and which under the microscope, with polarized light, is seen to be mostly composed of a glassy material; but even in this case the microscope also shows small crystals imbedded in the glass. Such rocks, in which glass is the chief ingredient, are called *glassy*.

The truly holocrystalline rocks we must leave for



FIG. 13. SECTION OF A CRYSTALLINE ROCK OF *DOLERITIC* TYPE.

a later lesson; but as an example of one that is nearly holocrystalline, and is seen without the aid of the microscope to have a decidedly crystalline look, we may take the rock called *Dolerite* (see Fig. 13).

It is a coarse-grained rock, and a freshly-broken face glitters with what are obviously either the faces or the cleavage surfaces of crystals. Some of these are transparent or colourless; others are dark-coloured, and others

black, so that the rock as a whole is dark. Under the microscope the colourless-looking crystals are seen to be lath-shaped, striped feldspars, with the bands alternately dark and light under polarized light. This shows that they are not potash feldspar. The darker mineral is augite. It occurs in broad plates, mostly irregular in outline, but sometimes in shapes like that in Fig. 14. Two sets of fairly straight cracks, all the cracks of each set being parallel, cross each other nearly at a right angle, one set being more regular and continuous than the other. These are the edges of the cleavage planes. With ordinary light, in a thin slice the mineral is generally of a faint tint, but it becomes brilliantly coloured under polarized light. Grains of another material also catch the eye, on account of their very vivid colour under polarized light. These are olivine. With ordinary light their surface looks rough, like ground glass. They are cracked in all directions, but the cracks are not straight cleavages, but run in the most irregular fashion. Some of the olivine is more or less changed into serpentine. This is seen in some of the grains in which the cracks are edged by a border of fibrous stuff that is grey and white under polarized light. These are serpentine, and we have here the beginning of the change which starts along the cracks. As the change works its way inwards, the border widens, till at last nearly all the mineral is turned into a mass of greyish, fibrous, or gummy-looking serpentine, in the middle of which a few points or 'eyes' of olivine still remain and retain their vivid colouring.

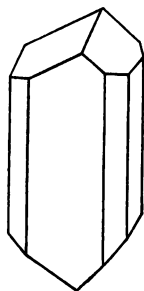


FIG. 14. A CRYSTAL OF AUGITE.

Scattered all over the slide are little black specks of

magnetite, while between the crystals there may be stuff which we cannot distinguish from glass, though it may be partly cryptocrystalline, or be wanting altogether.

As an example of the cryptocrystalline rocks we may take the commonest of these, which is known as Basalt. It is black and heavy, and so very closely grained, that though here and there a little glittering crystal may be detected by careful scrutiny on a freshly-broken surface, the great mass of the rock looks so smooth and even that no inexperienced person would for a moment think of calling it a crystalline rock. But put a slice under the microscope, and we see that the whole is a felted mass of small crystals; some are long, narrow laths, with fairly straight sides and usually irregular ends, crystals that could not build themselves into perfect shapes, because they got in one another's way while they were forming. With polarized light they show the same banding as the crystals in dolerite, to which they correspond. The minerals augite and olivine are also present, but generally in such small grains that the beginner cannot easily recognize them; but magnetite grains are easily noticed by their opaque, black colour. But if we look carefully we shall see that basalt is not altogether made up of the crystalline minerals just mentioned. There are spaces between the crystals, and these are filled with a very fine matrix or ground mass, in which we cannot separate any parts or grains except with very high magnifying powers. This ground mass is sometimes glass, or partly glass.

We thus see that the only difference between basalt and dolerite is that one is more coarsely grained than the other. This is mainly due to the fact that dolerite cooled more slowly than basalt.

Another very common cryptocrystalline rock is called *Felstone*. Only one point about it need be noticed here.

It is sometimes so closely grained that it reminds one of flint, and the unaided eye can detect not the slightest sign of a crystal in it. But the microscope shows it to be made up of very small crystals or crystalline grains of quartz and felspar. There are reasons for believing that many felstones were once glassy, and that they have been rendered crystalline gradually, a change which is known as devitrification, and this explains one curious point. All felstones are old, and in the old rocks it is the rarest thing to meet with a glassy rock, while in rocks that are younger glassy rocks are plentiful. The fact, no doubt, is that when these older rocks were formed, there were plenty of glassy rocks amongst them; but during the enormous length of time that has passed away since their formation, glassy rocks have been devitrified, like the bottles in Etruscan tombs—only in the bottles there has been time to devitrify no more than a thin layer outside, while these older glasses have now been devitrified right through.

As an example of a truly glassy rock we may take pitchstone, such as can be found in the Island of Arran (see Fig. 15). It is black and compact, and though dull like pitch, it is hard like a glass and to a small degree transparent. Now look at a thin section of it under a microscope. Cross the nicols. The greater part of the slide is dark, and remains dark, while the stage is turned quite round; it is therefore glass. But scattered through this there are slender hair-like bodies, sometimes beautifully branched and moss-like, which let the light through, and are therefore crystalline. These are arranged more or less in wavy lines, running mostly in the same direction, as if they were floating down a river, and there cannot be a doubt that the rock was once liquid and flowed in the direction of these lines. In some cases we find amongst

all this some larger bodies which let the light through and perhaps produce colours. These are crystals, and occasionally show their shape. In this case the lines of flow open out, pass round the crystal, and come close together again on the other side. Such a structure is known as *fluidal* structure. As the rock is mainly glassy it must have cooled quickly. But how about the large crystals? They require time and slow cooling, one would

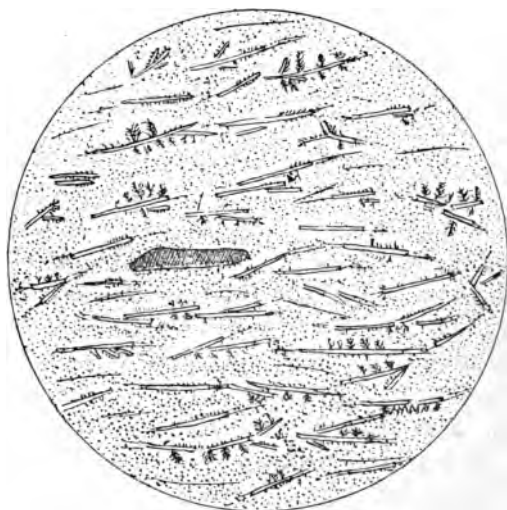


FIG. 15. SECTION OF PITCHSTONE FROM ARRAN.

think. They must therefore have been formed under different conditions from the rest of the rock, and they have been brought into the then liquid glass and borne on by it as it ran. That this was so, is shown by the fact that these larger crystals are sometimes broken, as might well happen as they were dragged along, and they sometimes look as if they had been eaten into, which is due to the fact that the glassy material is of a corrosive

nature, and has eaten away parts of the crystals. Such crystals are called those of the first consolidation, and the hair-like crystals those of the second consolidation.

But we cannot find out all the characters of these rocks, nor discover what they are associated with by merely looking at small pieces of them, but we must go out of doors and examine them in the field.



FIG. 16. SLOPES OF CONTEMPORANEOUS LAVAS AND TUFFS, SOUTH OF KESWICK.

One of the best spots to go to for this purpose lies on the hill-slopes on the east of Derwentwater, south of Keswick. There a number of beds of rock come out along the hill-sides, which to the unaided eye and under the microscope are made up of very much the same materials as basalt and dolerite. The upper part of each

shows a number of bubble-shaped holes, all drawn out in the same direction. This part is known as the vesicular top. Some of these holes are empty, but others, which are obviously of the same kind, are now filled up with a white or pink substance, very different from the dark rock which surrounds them. They look like imbedded almonds, so the rock in which they are found is said to have an *amygdaloid structure*. Some way further down the holes become fewer and smaller, and a little lower still disappear altogether. Parts, also near the top, show a wrinkled and knotted appearance, like the surface of an iron-slag, and this is known as slaggy structure. Lower down the rock is smooth and closely grained, and the microscope shows it to be cryptocrystalline ; still lower down we find larger crystals.

Between these crystalline rocks are beds made up of broken fragments, some of which are bits of the slate that lies underneath, while others are ragged pieces of vesicular rock. These are generally spoken of as *ashes*. There are also beds of a peculiar fine grain made up of material like the grinding down of the crystalline rocks, and these are called *tuffs*.

All these varieties are often interbedded with ordinary sedimentary rocks such as sandstones, shales, and limestones, and have their surfaces throughout parallel to the planes of bedding, in which case they are called *contemporaneous*.

At other places we find basalt and felstone running like a wall across the sedimentary rocks, or in some cases running nearly parallel to them, and then after a while crossing from one bed to another. In this case the rock looks in many places very like a contemporaneous sheet. But it has come there in a very different way from a contemporaneous sheet, for it occupies cracks in the rocks, or

intervals between two beds, both of which were there before it came. The contemporaneous sheet, on the other hand, was formed later than the bed on which it rests, and the bed above was not laid down till afterwards.

These rocks, which at some part or other cross the bedding of the sedimentary rocks, are called *intrusive*; when they are nearly perpendicular to the bedding, so as to look like a vertical wall when the beds are flat, they are called *dykes*; when they are nearly parallel to the bedding they are called *sills*.

There are many signs by which we can usually distinguish one kind of sheet from the other, the most important being these. There will be little or no vesicular structure, as a rule, in an intrusive sheet. There are no ashes or tuffs associated with these intrusive sheets.

In some places we find rocks like those we have been describing in quite a peculiar form. For instance, in the neighbourhood of the contemporaneous sheets and ashes of Keswick, there is a kind of plug of the basaltic type of rock running vertically down into the earth—it forms a hill called Castle Hill. For another instance, we find on the coast of Fifeshire, surrounded on all sides by a red sandstone, large circular patches of a fragmentary rock, in which the fragments are very large, and of the same mixed kind as those found in the ashes. These patches are seen to be the filling up of round holes that go vertically downwards through the sandstone. These vertical pipes of rock are known as *necks*.

There is one more structure so common in rocks of this crystalline type, that it cannot be passed over. Among well-known spots in which it is seen to perfection are the Giant's Causeway in Antrim, and Fingall's Cave in the island of Staffa. Here we have great sheets of basalt

which possess what is known as *columnar structure*. The sheets lie nearly flat, and running through them is a network of vertical cracks, which divide them up into long columns. The columns vary a good deal in shape—three-sided, four-sided, five-sided, six-sided columns, and even columns with more sides may be found; but there is a strong tendency for them to be six-sided, and the

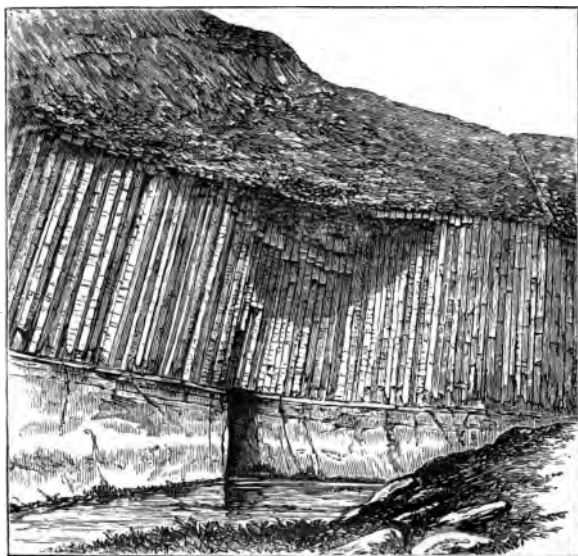


FIG. 17. COLUMNAR STRUCTURE IN BASALT, STAFFA.

cross-section of many of them is very nearly a regular hexagon.

A similar structure can be produced artificially in many substances, of which starch furnishes an excellent illustration. A mould is filled with a thick solution of starch in water; the water evaporates; the starch dries and contracts in drying; cracks are thus produced, and they break

up the starch into the most perfectly regular hexagonal columns.

There cannot be a doubt the columnar structure in rocks was produced in a similar way. The basalt has contracted in size since it first came to be where we now find it, and the shrinkage cracks produced by contraction broke it up into columns. The shrinkage cracks in starch are singularly regular, because the starch is uniform in character throughout. The material of the basalt is not so uniform, and hence its cracks are not so regular in their arrangement.

The cracks produced in this way run at right angles to the bounding surfaces of the contracting mass, and, as we should expect, in a dyke they are found to be perpendicular to its walls, and in a contemporaneous or intrusive sheet, which runs nearly horizontally, they are up-right.



FIG. 18. PERLITIC STRUCTURE.

There is another very interesting structure, sometimes met with in rocks which are either now glassy, or were once so, and have been afterwards devitrified, which shows that these rocks have also contracted. The structure consists of a large number of circular cracks, as seen in a thin section, grouped round numerous centres in the rocks. The outer cracks overlap and run into the inner cracks obliquely. When this structure is very perfectly developed, it divides the rock into a number of pearl-like parts, hence it is called *perlitic structure* (see Fig. 18).

This also may be imitated. Take a glass slide and

grind one side rough on emery paper. Then pour over part of it some hot Canada balsam that has been heated long enough to turn brittle on cooling ; let it gradually get cool, and while it is still warm pour some cold water over it. On looking at it when cold, we find it divided up into parts by a number of curved cracks overlapping each other and arranged round centres, just as we have seen in the rock. In the balsam we know that these cracks are produced by the sudden cooling of the half-cooled mass, and it appears probable that the same structure in the rock was produced in the same way.

Another common structure especially characteristic of the more felsitic rocks may also be noticed. Many felstones show peculiar round spots, and these on weathering are seen to be sections of little spheres like minute peas, or occasionally much larger ; on examining the sections each sphere is seen to have a number of radiating lines, passing outwards from the centre, and these may be recognized under crossed nicols as crystalline in character. Such a structure is called *spherulitic*, and is thought to be a result of the devitrification of a glassy rock (see p. 129).

LESSON XIII

REASONS FOR BELIEVING THAT SOME CRYSTALLINE ROCKS AND THEIR ASSOCIATES ARE THE PRODUCTS OF OLD VOLCANOES

FROM what we have learnt in the last lesson, we know that the cryptocrystalline and glassy rocks present many peculiar features. But we do not find anywhere in the neighbourhood, nor even in England, any place where such features are being now produced or have been lately produced.

Let us recapitulate the features whose origin we have to look for. We have seen that (1) the material of the rocks is crystalline or glassy, or both; (2) it has filled up cracks or spaces in the previously-existing rocks; (3) that it has a number of holes near the surface, some empty and some filled up, and is more coarsely crystalline below; (4) that larger crystals are sometimes found amongst the finer material; (5) that the rock has contracted since it was formed more than the surrounding rocks; (6) that associated with these rocks we may sometimes find fragmentary rocks of mixed materials.

What, then, can have produced such features as these? Some of them we can certainly find amongst artificial products. Glass, for instance, which has a chemical composition of the same general character as the glassy rocks, both being silicates, is made, as we know, by heating the ingredients together in a furnace, so that at first it is

a molten mass, which flows along the surface it is poured on. Then, again, if we look at the slag which comes from an iron furnace, which is also a silicate, we find several of these features. The outside of the slag is glassy, nearer the centre it is mixed glass and fine crystals, and near the centre of a large mass we may find better-formed crystals, at least under the microscope. It flows, of course, along the surface of the ground, and will run into any crevice it may meet with. The surface here and there contains holes (which, however, are more abundant in the slag from a glass-works).

These are not all the features we have to account for, but the others may be due to the large scale on which the operations of nature are conducted, or to the time that has elapsed since the work was done. At all events, what we have to look for is obviously a natural furnace on a large scale. Now, we know that there are volcanoes in other countries, though there are none now active in our own country, and that out of these volcanoes come long streams of molten rock called lava, and from them are thrown up dust and fragments which, with the lava, accumulate round the orifice and build up the mountain.

We must go, then, to a volcanic region, and see if what we find there resembles what we find in and with these crystalline and glassy rocks whose origin we are trying to discover. If we take a specimen from the body of a dark-coloured lava-flow, and compare it with a basalt or a dolerite, we shall find that they agree so closely in texture, and to a greater or less extent in composition, all of them being crystalline silicates, that we feel pretty sure on this ground alone that these rocks are old lavas. If next we search about, say, in the Lipari Islands, we shall find on the slopes of some of the volcanoes large masses of a dark, black, lustrous glass, which is known as

Obsidian. It breaks with a sharp conchoidal fracture, and the thin flakes are more or less transparent. Now, look at a thin section with the microscope, and you will find all the features of pitchstone, except that the hair-like crystals are not anything like so numerous and complicated, but there are the same occasional larger crystals, and the same arrangement of the small ones in lines of flow amongst the glass. There can be no doubt, then, that both have the same origin, but the formation of fine crystals, i.e. the devitrification, has proceeded further in the pitchstone.

But the other features of these rocks and their associates can be so closely matched amongst volcanic products that from a consideration of these resemblances alone we should conclude them to be of volcanic origin.

We cannot say exactly how volcanic action is brought about, but it must be somewhat as follows. Deep down beneath the surface there is an enormous reservoir filled with melted rock at a very high temperature. But it is not the great heat alone which keeps the rock melted. Mixed up with the molten mass there is water, or—perhaps it would be safer to say—something that becomes water when, later on, it comes up to the surface: ‘water-stuff,’ let us call it. Our reasons for believing that the water-stuff is there will soon be given.

Well, this seething mass as it swells, and the water-stuff as it expands, with the heat, press and struggle violently to tear a way out. At last the rocks above are rent asunder, and a fissure is burst open that reaches up to day. The pressure is thus lessened, the water-stuff turns to steam, and rushes out, just as happens when the boiler of a steam-engine bursts. The rocks adjoining the fissure are shaken all to bits by the rending and violent explosions, and the broken fragments shot up into the

air. The portions hurled out are of all sizes, from blocks weighing tons to smaller stones, and down to fine dust. The steam also, as it works its way up through the molten mass, tears off portions of it and tosses them up. They are not large, and therefore cool and harden quickly; frequently they are ragged like cinders, when they are called *scoriae*; sometimes they get a spin in their flight, and this rounds them into what are called *volcanic bombs*. All the various bodies that are thus thrown out accumulate round the orifice and form sheets of *volcanic ash* if they are coarse, and of *volcanic tuff* if they are fine. These resemble in all particulars the rocks associated, as before noticed, with the crystalline and glassy rocks which we can see in our own hill-sides. These latter we conclude, therefore, were originally thrown out on to the surface during a volcanic eruption.

The expansion of the steam also pumps up the molten matter to the top of the fissure; it runs out gradually, cools and hardens, and forms what is called lava. This spreads out like a coat over the surface of the ground; on this more ash accumulates, then comes another outflow of lava, and so on, till in this way the volcanic mountain is built up.

The lava may run for many miles before it becomes too hard to flow any further, and its great sheets have sundry points about them which distinguish them from sheets or layers of any other kind of stone. Fig. 19 will make this clear.

First steam comes out of the lava in enormous quantities. It cannot have got into the lava after the lava was poured out; it must have come up from below with the lava, and this is one of the reasons for believing that water or water-stuff is mixed up with the molten matter underground.

At the top of the sheet there is nothing to check the escape of the steam ; it boils up freely, and blows out the liquid or sticky lava into innumerable bubble-shaped holes. As the lava flows on, it drags out these holes. The upper part, then, of a lava-stream is full of bubble-shaped holes lengthened out in the direction in which the lava is flowing. But this is just what we have recognized in the rocks whose origin we are seeking, and have called it the vesicular top. This peculiar feature common to the two rocks shows that the older one was originally poured out as a lava-flow ; and this conclusion becomes stronger as we examine further.

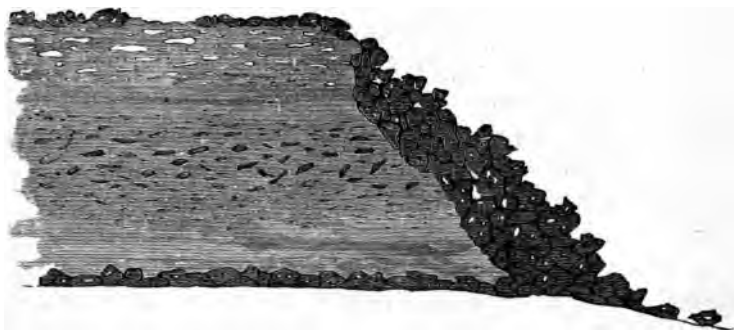


FIG. 19. STRUCTURE OF A SHEET OF LAVA WHICH HAS FLOWED OUT AND COOLED IN THE OPEN AIR.

In the parts of the stream some way below the top, the steam will not find it so easy to boil up. It will be kept down by the weight of the lava above it, so the bubble-shaped holes will be fewer and smaller below the top, and at last we come to where there was so much heavy lava above that no steam could boil up. Here, then, the bubble-shaped holes will disappear, just as we have seen that they do in the case of the Keswick rock.

The stream of lava also shows structures that are not so commonly met with in the old rocks, which we now

know were also lavas, though they may be occasionally seen.

The top of the lava-sheet cools faster than the interior, and gets pasty, while the inside is still fluid. Now, sticky bodies like treacle and pitch, when they run down a slope, often show a wrinkled surface. The same wrinkled surface may be seen on many lava-flows, and in both cases it is because the flow of the liquid mass beneath drags the pasty crust along, and so it becomes wrinkled, twisted, or knotted. This is called *slaggy structure*. Also a thin hard crust may form on the top while the stuff underneath is still liquid or pasty. The liquid part flows on, drags the crust with it, and breaks it up into ragged fragments, like cinders in shape. These fall over the front on to the ground, the liquid lava runs over them, and bends them together into what is called a *cindery base*. In the case of our old lavas, the pressure of the overlying rocks is apt to obliterate somewhat these features, but they frequently are more irregular at the top and bottom.

Also the rapid cooling at the top will tend to form glassy or cryptocrystalline matter there; the inside cools more slowly, and the hardened lava is likely to be made of larger crystals. But these will grow gradually larger as we get towards the middle. Some lavas, however, when examined soon after they have cooled, show crystals scattered through them of considerably larger size than the rest. These cannot have had time to form where they are found after the outflow of the lava, but must have come up already formed in the molten mass. These correspond to the crystals of first consolidation that are met with in the old lavas.

So we see that a large number of the peculiarities of our old rocks can be matched in the lavas and ashes

which we know to have come out of volcanic craters in our own day, and we conclude that these rocks must have had the same origin, though there is not now, and as far as human history goes back there never has been, anything like an active volcano in their neighbourhood. But all that we have seen at volcanoes has been at or near the surface, and in the neighbourhood of the volcanic mountain. In the case of our old rocks, this mountain has long ago been swept off the face of the earth by denudation, and only parts of the streams of lava which it sent forth have escaped and remain to the present day. But this denudation cannot sweep away the fissure out of which the lava and ashes have come, though these may be covered up by later sedimentary deposits. On the other hand, so long as the volcanic mountain is there, we cannot see this fissure or pipe so as to examine its contents. Still, we know what has come out of it, and we may be sure that the same kinds of material fill it up when the steam has no longer sufficient power to drive them out. We must wait till the mountain is gone to see them. We may expect, then, to find occasionally, somewhere near the old lavas, such pipes, and we actually do see them in what we have called necks, so that we can now call them volcanic necks, meaning that they mark the spot out of which the volcanic material of the neighbourhood has come to the surface.

We can now very easily see what has happened in the case of contemporaneous sheets, such as those near Keswick.

First a rock was formed under water out of mud, sand, or limestone; then a lava-stream flowed over the top of these, or a layer of volcanic tuff was showered on to them. Then more sediment was carried into the water, settled down, and formed the beds; over these a second

lava flowed, and so on. The hill-side contains a history of alternate volcanic eruptions and sedimentary deposit. Taking the whole period during which this went on as a unit of time, the two sources of rock-formation were active during the same unit, and in this sense they are called contemporaneous—to speak more exactly, they might be called *interbedded*.

We have yet to explain how the dykes and sills are formed. The latter cannot be seen in a modern volcano, because they run underground, and we have to wait for denudation to expose them. But where a later eruption has broken down the sides of an old volcano, as in the case of Monte Somma round Vesuvius, and the Val del Bove on the side of Etna, the great vertical walls which run through the ashes are well seen. We can easily understand how these are formed. Much of the lava runs underground without coming up to the surface. The rending of the rocks tears open long cracks across them; the liquid lava is pumped into these, and fills them up. If the crack is nearly vertical, we get a dyke; if nearly horizontal, we get a sill. In these cases, when the lava was driven in, there was rock at the sides or above, which was strong enough to prevent the steam from boiling up.

Here, too, we find the columnar structure, which we have learnt is due to contraction. We now know that the contraction is caused by the cooling of the molten lava between two immovable walls. It cannot sink down bodily, or draw itself away from the walls of the fissure to which it is glued, so it cracks across in regular joints, which form columns running at right angles to the cooling surface. When there are no such surfaces, and the rock is glassy, the cooling may produce the smaller cracks which produce the perlitic structure,

which is found, though rarely, in some of the older obsidians.

The only other structures that remain unaccounted for, are the filling up of the vesicles in the lava, to form an amygdaloid, and the devitrification of the glass. The latter appears to take too long a time to be produced in modern volcanoes. It is really a process of very slow contraction, as the same material, when it forms into a crystal, occupies less space than when it is in the form of a glass. The former may be easily recognized in the older lavas—say, of Etna. In these we find some of the vesicles empty, and some of them filled with the same sort of minerals as occur in the filled-up vesicles of the old lavas, where the volcanic mountain may have disappeared. These minerals contain a considerable proportion of water, and are no doubt formed by water percolating through the rocks, leaching out the silicates from the lavas on their route, and redepositing them again in the empty spaces in which the water accumulates. It thus appears that all the peculiarities of the rocks we have been discussing, with the exception of those which obviously take a very long time for their production, can be matched among the products of modern volcanoes, and we are thus justified in applying to all such rocks the general title of VOLCANIC ROCKS.

LESSON XIV

OF THE ROCKS CALLED PLUTONIC

WE will now go on to those crystalline rocks which are holocrystalline in the highest degree.

Procure from a dealer a specimen and slide of ordinary Cornish granite. It is whitish in colour, but blotched with spots that are not so white, and here and there are glittering surfaces. The whitest parts are more or less opaque, and if the specimen be fresh we shall find that they can just be scratched by a good knife, and have flat surfaces. These are potash felspar. There are also lumps of a clear, transparent mineral, breaking with an irregular surface, which cannot be scratched. These are quartz. The little brilliant spangles may be either white or black, mostly the latter. They are very soft, and with the point of a knife you can split them into the thinnest flakes. These are mica. Other crystalline minerals fill up the spaces between the larger crystals and lumps, and even with the unaided eye it can be seen that the rock is wholly made up of crystals or crystalline lumps. There is nothing like the finely-grained paste of basalt or dolerite, nothing like the glass of obsidian.

In the microscopic slide (see Fig. 20) some at least of the felspar crystals look muddy, because they have begun to change into china-clay; and in some can be seen parallel cracks, which are the edges of cleavage planes. Some of them are seen to be made up of two parts, which are

coloured differently in polarized light. The mica, if seen on the surface of its plates, is highly coloured between crossed nicols; but seen in any other direction, is crossed by a number of fine parallel lines lying close together, which are the edges of the cleavage planes; their ends are frayed out; they are also dichroic (see p. 122). There may also be found some smaller crystals of the same kind of



FIG. 20. SECTION OF GRANITE.

a is felspar; *b* mica; and *c* quartz. The dark shading in the centre represents mica-flakes.

felspar as we had in dolerite, with many parallel bands, which are coloured differently in polarized light. The quartz may be easily distinguished. In ordinary light it is clear, though there may be dirt scattered about in it; but this is evidently something foreign that has got into the quartz, and is quite different from the muddiness of the altered felspar. It is cracked, but the cracks run irregularly, and not in parallel straight lines like cleavage

cracks. But the most important point about the quartz is this. The felspars, though they are not in perfectly-shaped crystals, have a tendency towards being crystals, that is to say, their longer edges are in many cases straight, and in a few there are pointed ends. But the quartz, though crystalline in substance, does not show any sign of crystal outlines. It runs in and out among the imperfect crystals of the other minerals, and fills up the spaces between them. This means that when the rock was in the process of crystallization, the felspars and other minerals crystallized out before the quartz. The quartz was the last mineral to become solid.

And now can we form any reasonable conjecture how such a rock as this was formed?

First, it is to be noted that there are rocks, which are unquestionably lavas, that have the same chemical composition, and are made up of the same minerals, as granite, but they are never so largely and thoroughly crystalline; they may be glassy in part, or cryptocrystalline, or even porphyritic; but they have always more or less of matrix or ground-mass; they are never holocrystalline. Now we know that slow cooling favours the formation of large crystals; and if the contents of the reservoir beneath a volcano were allowed to cool where it is, instead of being pumped up to day, the cooling would be very slow, for they have above them a great thickness of rock through which the heat must pass before they can cool. Now, as the rock is a bad conductor, the heat would pass off very slowly. Cooling slowly, then, it is highly probable that the granite magma will harden into a holocrystalline rock.

Now we know that volcanoes do not go on erupting for ever; they go out or become extinct, because the material below cannot force its way out. When this

happens, the contents of the reservoir will cool where they are.

As we know, then, that rocks of the character of granite must be formed beneath every volcano, though the composition and minerals may, and must, vary with the kind of lava that the volcano, when active, poured out, it appears in the very highest degree likely that granite and other similar holocrystalline rocks have been formed in this way, though from the very nature of the case we can never expect to see the process in operation. There are lavas which are made out of the same raw materials as granite, but the process of formation has been different in the two cases. In the case of the lava, the material was pumped up to the surface of the ground, and cooled quickly; in the case of the granite, the material remained where it was, deep down below the surface, and cooled slowly.

And there are other features about granite which makes this explanation of its origin more likely; granite is never vesicular. When the lava reached the surface, the water-stuff that was in it boiled up and blew out the bubble-shaped holes. But above the reservoir in which the granite hardened, there lay a thick mass of rock, so heavy that it prevented any boiling up of steam. Nevertheless, though no steam was formed, we can find good reasons for believing that the water-stuff was there, mixed up with the molten matter. If any were present, it is plain that it would accumulate mostly, as the crystallization went on, in that part of the magma which was the last to crystallize, and we must look for signs of its presence in the quartz. If we look with care in this mineral, letting the light fall on it in different directions, we shall see that many of the dark dots, which look at first sight like specks of dirt, when more highly

magnified, are in reality small hollow spaces partly filled with water, especially those dots which run in lines through the mineral. Many of these small hollows have one or more bubbles in each, which dance and race about through the water. As the quartz crystallized, it grew round small portions of the water-stuff and shut them in. At first, while the rock was still very hot, though solid, the hollow space was filled with water-stuff; as the rock cooled, this turned to actual water, and contracted in doing so, so there was not water enough to fill the hollow space, hence the bubble. These hollow spaces are called

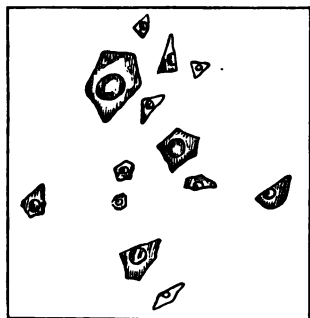


FIG. 21. FLUID CAVITIES IN QUARTZ.

FLUID CAVITIES. They are almost always found in the crystals of holocrystalline rocks; scarcely ever in the smaller crystals of lava, because when the lava came up to day, the water-stuff turned to steam instead. They are found, however, as we should expect, in some of those larger crystals in the lava, which we

have found reason to believe were formed in it before it erupted.

The presence of this water-stuff in the molten matter of the reservoir beneath the volcano, leads us to ask what are the means by which this magma is made fluid. There are three ways in which a solid can be turned into a fluid. First, by heat alone, as when we melt iron in a furnace, called the DRY WAY; secondly, by dissolving it in a liquid, as salt in water, called the WET WAY. It was by neither of these ways that the contents of the reservoir were kept liquid. There was intense heat, but

there was water-stuff as well, and each helped the other. This is called the HYDROTHERMAL WAY. Now, it is plain that this hydrothermal way is only possible when the molten mass is shut up, for if it were not shut up the water-stuff would turn to steam and boil off. According to our explanation of granite, the magma of which it is the crystallized form was duly shut up. We have shown also the presence of water, and there is a further reason for believing that it was not dry heat that kept the stuff liquid. We have seen that in granite the quartz crystallized out after the felspar. Now, it takes a much greater dry heat to melt quartz than to melt felspar, so that as the cooling went on the quartz would have to crystallize while the heat was still great enough to keep the felspar fused, and the quartz would therefore crystallize first instead of last. As this is not the case, there must have been water-stuff in the magma to keep the quartz liquid to the last.

Rocks formed in this way are called PLUTONIC, from Pluto, who was king of the underground world. The commonest of them all is granite, but there are others beside. Such a rock is that called *Diorite*. This rock is darker coloured and heavy, and usually only two minerals can be detected in it by the unaided eye; one of these, which gives it its special character, is dark green. It is hard, but not so hard as felspar, and when you try your knife on it, it feels easier to scratch. It has one very marked cleavage, which makes it platy, and usually a second cleavage can be seen, which cuts the first cleavage at an angle very different from a right angle. This is hornblende. Its usual shape is shown in Fig. 22. The whitish or greyish crystals that are interspersed with this are felspar. These are the two principal ingredients, but in some specimens there may

be some quartz and other minerals that we need not mention.

In the microscopic slice the hornblende is very conspicuous by its colour. Some sections of it show well-shaped crystal outlines derived from the form shown in Fig. 22, other sections have irregular boundaries. But in both cases two sets of very well marked and fairly parallel straightish cleavage cracks run across the mineral, cutting one another very obliquely. In augite it will be remembered that the cleavage cracks are nearly

at right angles, and this is one way in which the two minerals may be distinguished. Tested in the same way as the dark mica, the mineral is strongly dichroic. The felspars are striped like those of dolerite.

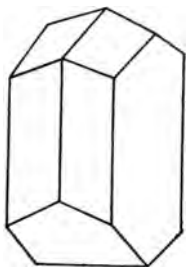


FIG. 22. CRYSTAL OF
HORNBLLENDE.

It seems probable from their general composition that granite represents the underground condition of the felsites, while the diorites and allied rocks repre-

sent some of the dolerites and basalts.

An intermediate plutonic rock is called *Syenite*. It is made up mainly of potash felspar and hornblende, and may or may not contain quartz as well.

Our account of the origin of granite, and other holocrystalline rocks, by the cooling of a magma contained in great reservoirs that exist beneath volcanoes deep down under ground, may seem difficult to accept when we see the granite at the surface. But this is because, after these rocks had become cool and solid, they were raised up in a way we shall explain by-and-by, and as they rose, the rocks that lay above them were swept

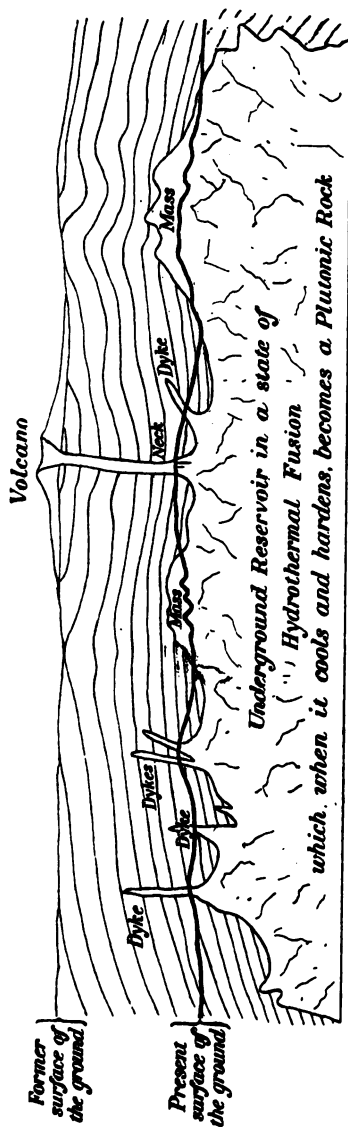


FIG. 23. THE RELATION OF PLUTONIC AND VOLCANIC ROCKS TO EACH OTHER.

away by denudation, and what was once deeply buried is now exposed to view.

These plutonic rocks are not found in sheets like lavas, but in great irregularly-shaped masses, from which may run out tongues into the surrounding sedimentary rocks. Whole groups of mountains are sometimes made up of a plutonic rock. Dartmoor, for instance, is all granite, and in Saxony and Bohemia there are still larger masses. The great size of these plutonic masses shows how enormous the reservoirs under volcanoes sometimes are, their area being measured by hundreds of square miles.

The relation of all these crystalline, glassy, and associated rocks to one another is shown diagrammatically in Fig. 23, which will be readily understood from what has been stated in the present lesson.



LESSON XV

HOW ROCKS HAVE BEEN BENT INTO FOLDS, PUCKERED AND BROKEN ACROSS, AND MOVED FROM THE PLACES IN WHICH THEY WERE FORMED.
WHAT IS MEANT BY UNCONFORMITY

THE furniture and ornaments of our houses were not made in the places where they now stand, and a moment's consideration will show that this is also true of the rocks of the earth's crust. They have been moved out of the workshops in which they were produced. For it was beneath the water of the sea that a very large part of them was made, whereas we now find them high and dry on land, and not unfrequently forming the tops of mountains, thousands of feet above the sea-level.

And this is not all that has happened to ~~them~~ ^{the rocks}. At first they lay in great level sheets spread out one above the other. But a very little outdoor work shows us that they rarely lie in this way now. Let us go to some place where the position of the rocks may be easily seen on a large scale, as, for instance, the Pass of Llanberis, and note how the beds of rock are lying on the flanks of Snowdon on the one side, and of the Glyders on the other. For some distance the beds rear up at very steep angles, and what slope they have is to the south-east. After awhile the slope becomes less and less, till for a short distance the beds are lying flat.

They then bend up again, but now in a direction opposite to that which they had at first, for they slope to the north-west. Then they bend down again and slope once more to the south-east; and so they go on, rolling up and down again and again in a long succession of troughs and arches. These bendings of the beds are not of course so clear and distinct as they are drawn in a diagram; careful attention is required to make them out close at hand, but on a clear day they may be traced at a distance from the opposite side of the valley. If we notice how folds can be produced in a piece of flat paper by squeezing the sides together, we can easily see that the whole country has in like manner been squeezed together as in the jaws of a gigantic vice, till what were once level beds have been made to sweep up and down in fold after fold.

After having seen such unmistakable evidence of folded rocks in a mountainous region, we may be led to ask whether the rocks of the flatter parts of our country are folded in the same way. Here it is by no means so easy to make out how the beds lie. We have no bare mountain-sides and precipices on the face of which the beds can be followed, almost without a break, for miles. We think ourselves lucky if we get here and there a quarry, a railway cutting, or some such opening, which gives a clean-cut face to show us how the rocks are lying. The actual exposures of rock are far apart, and between them the solid rocks are more or less completely hidden from our view by turf or soil.

What a geologist does in such a case is something of this sort. He makes what are called traverses across the country, that is, he picks out certain lines, walks along them, and notes all that he sees in quarries and other sections. He uses these notes to construct a

general longitudinal section in the way which is illustrated by Fig. 24.

A, B is the surface of the ground. The strong lines show how the rock is lying in each natural section he has examined. Next, he has to fill in the gaps between these exposures. These exposures are his fixed points, about them he can have no doubt; the filling in is more or less theoretical. But if he has seen many actual sections, and if they are not very far apart, it is easy for him, after a little practice in the work, to see that there can be only one possible way of filling up the gaps. If he finds a bed of

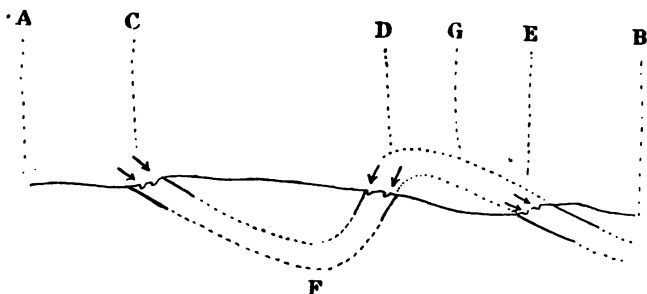


FIG. 24. CONSTRUCTION OF A LONGITUDINAL SECTION.

rock running underground in the way shown at *C*, and if what he is sure is the same bed rises up again in the way shown at *D*, there cannot be any doubt that its course underground must be something like what is shown by the dotted lines *F*. If, again, the same bed is found further on plunging down underground as at *E*, he feels equally sure that this bed once rose up into an arch between *D* and *E*, such as is shown by the dotted lines *G*, and that the part of this arch which lies above the present surface of the ground has been swept away by denudation.

Let us take an actual case, and try to make a longitudinal section from Oxford to Brighton. Passing over

the flat ground to Didcot we reach the chalk, and at Brighton we end on chalk, but it is not chalk all the way. Near Didcot we find several railway cuttings, and at first they are all in chalk, and it is easy to see—as, for example, in the cutting at Moulsoford Station—that this chalk is sloping down towards the south-east, though the slope is very small. The same is repeated in many other cuttings. But about Reading we begin to lose the chalk, and we may see it passing down below some overlying sands and clays. Over a broad space of country every opening that we come across is in these sands and clays, which we must look at carefully, so as to be able to distinguish them from other sands and clays. Some way north of Guildford a change takes place, and chalk is seen rising up again from underneath these sands and clays. Here it is seen to slope to the north-west, or exactly in a contrary direction to that in which it sloped when we last saw it. The slope is also greater than at Didcot, and produces the narrow, elevated ridge known as the Hog's Back. Can there be any doubt that the chalk runs underground somewhat in the way shown in Fig. 25? That it actually does so, is made certain by the fact that wells and bore-holes between Reading and Guildford have gone down through the sands and clays which reach the surface and have found the chalk beneath them. Our further course lies across the Weald of Sussex. Almost immediately after leaving Guildford, we come to some more beds of sand and clay, but these are quite different from those on the other side of the Hog's Back, and they may be seen to come up from beneath the chalk. Bed after bed, each with its own character, always sloping more or less to the north-west, is crossed, till the centre of the Weald is reached, where

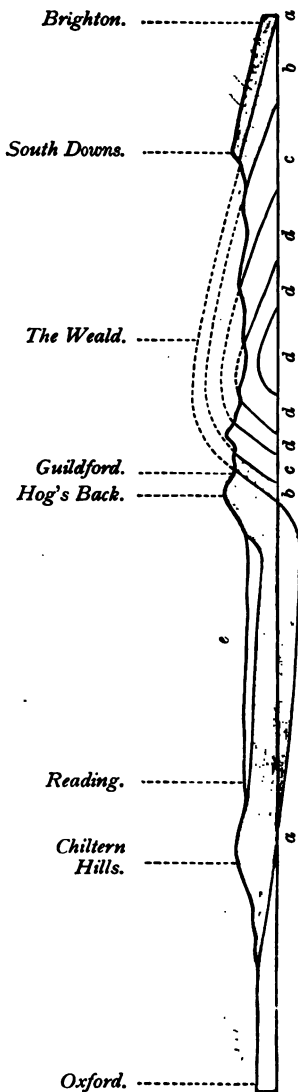


FIG. 25. LONGITUDINAL SECTION FROM OXFORD TO BRIGHTON.

Chalk; b Gault, &c.; c Lower Greensand; d Wealden Series; e Tertiary.

we are unable to trace the bedding. Continuing our journey, as the South Downs are approached we find the same sort of rocks again that we saw on the south of Guildford, till about some seven miles to the north of Brighton chalk reappears. It is here sloping gently to the south-east, and is distinctly seen to lie above the sands and clays of the Wealden District. It is this chalk that forms the mass of the South Downs. We cannot doubt, after all this, that there once was chalk all the way between what is now the Hog's Back and the South Downs, and that it lay in an arch such as that shown by the dotted lines, and that the dotted part has been worn away by denudation. All the beds that we have seen between these two places show the same thing, by their reappearance on the two sides of the centre of the Weald, with slopes in opposite directions.

Here, then, we have a case, on a large scale, where beds have been folded into arch and trough as we found them to be in North Wales. True, the arches and troughs are here miles across instead of a few hundred yards, and the slope of the beds is for the most part very gentle instead of very steep.

As the results are so much alike, we can safely conclude that the causes have been the same; and if the folding in Wales was caused by squeezing, these feebler folds were produced in the same way, only that in this case the squeeze was a more gentle one.

But not everywhere more gentle, for the force that turned up the Hog's Back at a sharp angle must have been comparable in power to that which tilted up the beds in Wales. We find, indeed, in various parts of the world, sharp and gentle folds affecting adjacent parts of the same set of rocks, as shown in Fig. 26. On the left the beds are but slightly folded, bent into broad flat

arches, with similar broad flat troughs between them. As we travel to the right we see the folds growing narrower and steeper, till at the right-hand end we come to complicated and very sharp foldings. There is so gradual a passage from the scarcely-perceptible curves on the left up to the sharp crumplings on the right, that one can hardly doubt that they are all different parts of the same bit of work, and all produced by the same cause.

What is seen in the two cases just described is seen whenever and wherever we take the trouble to make a careful longitudinal section across a country. *The rocks are always found to have been bent into a succession of arches and troughs.*

And there can scarcely be a doubt that the bending in all cases has been brought about in the same way. The beds lay flat, to begin with. Their ends were forced together by a horizontal thrust; when the squeeze was powerful they were forced into sharp folds, when it was more gentle they were bent into broad sweeps.

Let these facts be thoroughly grasped and always borne in mind. They are leading principles in Geology. In connexion with these folds there are some technical terms commonly used by geologists, which we will now explain. In our above description we have used the

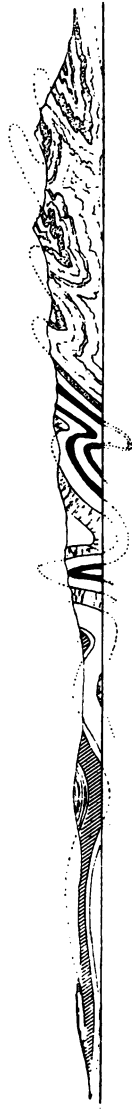


Fig. 26. SHARP AND GENTLE FOLDS PASSING INTO EACH OTHER.

general word slope, but a geologist would speak of the DIP. If we take a sloping bed, the line of steepest slope on its surface along which water would run down, is the line of dip; and we notice in every case its *direction* in relation to the points of the compass, and its *amount* in relation to the horizontal surface beneath it. If the rock were partially covered by standing water, the surface of the water would join it along a horizontal line perpendicular to the line of dip. This is called the direction of the STRIKE, or level-line (see Fig. 27).



FIG. 27. DIP AND STRIKE.

Where beds have been bent up into a long arch, it is called an ANTICLINAL or SADDLE; where they have been bent down into a long trough, it is called a SYNCLINAL or TROUGH. Where the crest of an anticlinal has been sliced off by denudation, as shown

by dotted lines in Fig 26, we have an *air-saddle*.

The folding and squeezing of the rocks cannot have been carried on without producing enormous strains in them, and in many cases these were so severe that the rocks have snapped asunder and cracks are produced. The simplest form of crack occurs amongst those rocks which have not been so severely treated, and which are brittle enough to break rather than to bend. If we examine a quarry in limestone or thick-bedded sandstone, we find that it is not unlike a room. The surface of the plane of bedding forms the floor; the walls are vertical and nearly at right angles to each other, though they have been untouched by the quarrymen. They

are the faces of natural cracks, known as JOINTS. When joints run through bed after bed, and range for long distances, they are distinguished from shorter and less regular cracks by being called MASTER-JOINTS. Master-joints are not far from perpendicular to the bedding, and when we measure their directions we often find that they group themselves in two sets: one set all run roughly parallel to the strike of the beds, those of the other set not far from the direction of the dip.

In Fig. 28 we have a quarry, where jointed structure

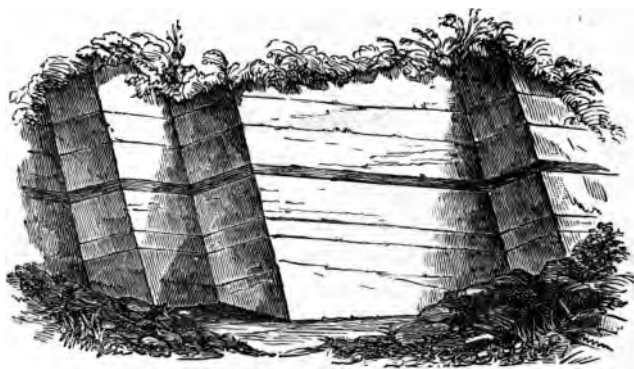


FIG. 28. QUARRY IN JOINTED ROCKS.

is clearly shown. The nearly horizontal lines are the edges of the planes of bedding. The nearly vertical faces on which the light falls are the joints of one set; those in shadow, the joints of the other set.

Experiments of the following kind make it likely that these cracks were caused by a stress that gave a twist to the rock. Take a strip of glass, about one inch broad and three or four inches long, and gum paper on to one side. Hold one end fast in a vice, grasp the other end between the thumb and first finger,

protecting them with a glove, and give the glass a gentle but steady twist, gradually increasing the pressure till a crack is heard. The glass will be found covered with cracks, and usually they lie in two sets, and run very much in the same way as master-joints in rocks.

Other forms of cracking are found in rocks which must be due to a different cause. Such are the joints in columnar structure, which instead of running at right angles are arranged to form a hexagon, as explained on page 134, (see Fig. 17).

In most cases the two sides of a joint correspond across the crack, and we can trace a particular band on one side, continuing its direction on the other side without any shifting; but in some cases the rock is not only fractured, but dislocated, and one side of the crack has been pushed up or has slipped down.

Such cases are very commonly seen in coal-mines, as is shown in Fig. 29. The dark band may be a bed of coal, and the dotted beds may be sandstones. These run on regularly up to the left-hand crack. On the right-hand side of the crack we find a bed of coal and a bed of sandstone agreeing in every particular with those on the left-hand side, but they have been dropped to a lower level. There can be no question that the beds were once continuous. Then came the crack, and either the rocks on one side were let down lower, or the rocks on the other side were pushed up higher.

Such a dislocation is known as a **FAULT**. The difference between the level of the same bed on opposite sides of a fault (the line *AB* in the figure) is called its *throw*. The amount of throw in different faults varies very much. In some of the Westmoreland slates they may be only a few inches, and specimens showing them are small enough to be exhibited in museums. In other cases we

are able to show that the throw must be some thousands of feet, and between these two extremes there are faults of all intermediate sizes.

It is very common to find a second fault near the first, letting down the intermediate rocks into a kind of trough. Such a pair are called *trough faults*.

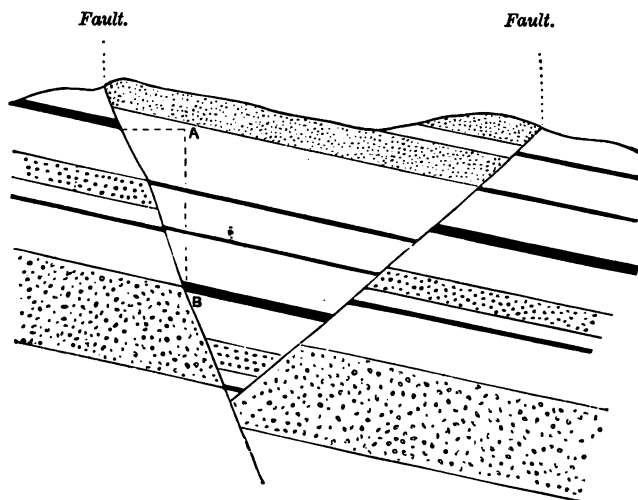


FIG. 29. FAULTS IN COAL-MEASURES.

In Fig. 29 the planes of the faults are not vertical, but incline to the right or to the left. The inclination of the fault to the vertical is called its *hade*. It will be seen also that the corresponding beds are lower on the side to which the fault inclines than they are on the other side. This is generally expressed by saying that 'the fault *hades* towards the downthrow side,' which is usually the case when the disturbance has not been very great.

In mountainous districts, and others whence moun-

tains may have been removed by denudation, we find the rocks to have been much more violently treated than in any of the cases yet described.

Some of the results are illustrated in Fig. 30.



FIG. 30. FOLD FAULTS.

In the left-hand cut we must suppose that the beds lay at first in level sheets, with their ends resting against a great unyielding mass of older rock, which had been squeezed so often that it would give way no more. They were then subjected to some force which acted from right to left and bent the beds at first into an arch. This force went on acting after the arch was complete, and as there could be no yielding on the left, the right-hand limb of the arch began to be doubled under and the arch a little tilted over.

Further squeezing canted the arch over still more, and produced the state of things shown in the middle cut. Here note, first, that before the rocks were folded, the shaded beds always lay *above* the black bed, but now they are sometimes above and sometimes below. When found below instead of above, the beds have been completely turned over, and what is called *INVERSION*

has been produced. Secondly, it was in the limbs of the arch that the pressure acted most nearly perpendicular to the beds and tended most strongly to squeeze them thin. Here the black bed has been crushed down to a mere film, the bulk of it being driven up into the crest of the arch, where the bed is thicker than in its uncompressed state.

As a final stage, the strain may have become so great, that a fissure was torn through the rock; the part below the rent was pushed further to the left than the part above; and a fault, which is very oblique, was produced. The hade of this fault is in a direction opposite to that of the more common faults in Fig. 29. Hence it is called a REVERSED FAULT. Sometimes this sort of thing takes place on a tremendous scale, and masses of rock large enough to make whole mountains have been driven along over the crack for some miles away from the place where they lay at first.

The surface along which the motion has taken place is usually flat, and is therefore called a THRUST-PLANE. The best instances of thrust-planes are to be found in the north-west Highlands of Scotland. The discovery of these has led to the explanation of many things which were previously obscure.

Fig. 31 will illustrate what is here seen. The shaded part is what is left in the hills; the dotted lines represent the parts removed by denudation. The lowest bed is a crystalline rock (1), then comes a kind of sandstone (2), then a series of shales (3), then a limestone (4), above which comes the crystalline rock (1) again, followed as before by the sandstone (2). The question is, how did these last two get there? We cannot explain all the evidence here, but it is now known that the line *PQ* represents a thrust-plane. Originally the rocks were

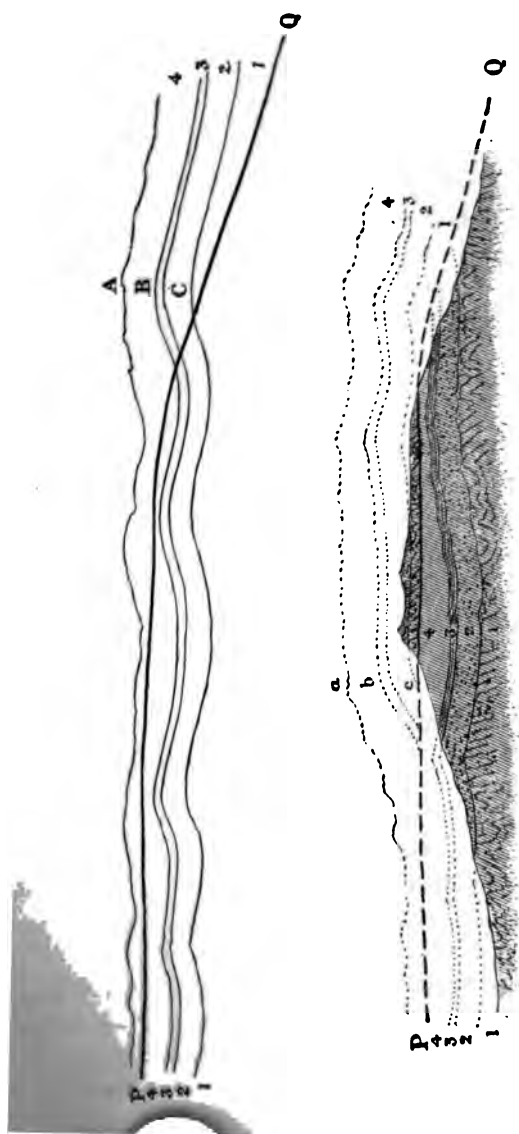


FIG 31. THRUST-PLANE IN THE NORTH-WEST HIGHLANDS.

in gentle folds, as represented by the upper figure. Then, by a force acting from right to left, a thrust-plane along *QP* was produced, and the part above it was pushed towards the left, and *A, B, C* in the upper figure came to occupy the positions *a, b, c* in the lower figure. After this most of the beds which overlay the sandstone were removed, and the connexion of the upper (1) and (2) with the lower (1) and (2) is no longer to be seen.

It is obvious that the plane along which a gigantic mass has been moved should show signs of enormous friction, grinding, and crushing of the brittle rocks, and much rolling and dragging out of those which were more yielding. This is always the character of a thrust-plane, as will be seen in the next chapter. On account of the importance of this mountain structure, another illustration will be given (Fig. 32).

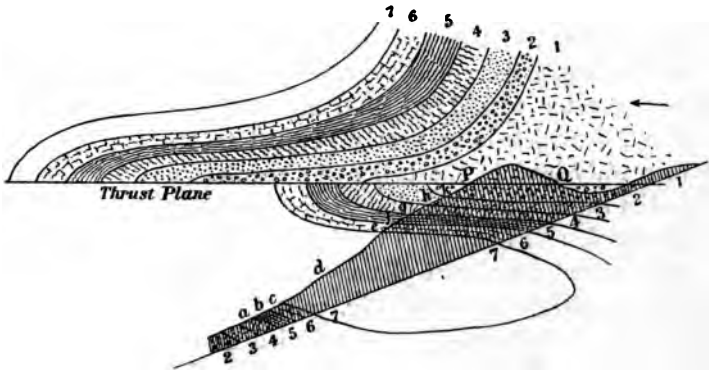


FIG. 32. INVERSION AND THRUSTING IN THE NORTH-WEST HIGHLANDS.

The shaded part here represents, as before, the rocks which can actually be seen. If we pass up the left-hand slope of the hill, and we find all the beds dipping the same way, we might well come to the conclusion that there was a regular succession with always younger

beds coming on as we go to the right, and that the youngest rock on the hill was the mass on the summit. But we should be wrong. It is the lowest bed of all.

To the left of *P* it will be seen that there are nine beds marked, because it is very necessary to look at them carefully. On the left-hand side the beds *a, b, c, d* represent the series of rocks in the neighbourhood, known to be in their natural order. Above we have a set of beds which come on so regularly over *d*, that one might easily take them to be additional beds overlying *d*. But when we look at them closely we find that *e, f, g* are really *c, b, a* repeated in a reversed order, that is to say, they are inverted, and must be connected underground as marked by the dotted line. So the beds *h* and *k*, instead of being higher in the series and overlying *g* regularly, are really (3) and (2), which originally lay under *g*. The mass *l*, if the trough is continued, should represent (1), and so it does; but instead of our finding on the right the commencement of the arch which we expect after a fold, we find a thrust-plane along the line *PQ*, which is so nearly parallel to the bedding as to readily lead to the belief in a regular succession. It is the same force that first produced the inversion, then the crack, and finally the motion of the upper half of the arch along the thrust-plane. The whole is a magnified representation of part of Fig. 30. The remainder of the fold is represented by the unshaded portion of Fig. 32, but it is no longer to be seen—it has all been removed by denudation.

Unconformity. Ages ago a Babylonish or Assyrian scribe sat down to trace in the language and letters of his time, on tablets of clay, a record of the events that day by day were passing before his eyes, and he piled the tablets in order, one above the other, as he filled

them up. So he and his successors pursued their task for many a long year. Then came an invader, war, and desolation. The city in which the historians had conducted their labours was sacked and burnt, their orderly heaps of tablets were overthrown, some utterly destroyed, some mutilated, and all that remained thrown into confusion, and what was left of the town became buried out of sight. Long afterwards a new city was reared on the same site, and, as it so happened, in this city there was a scribe's chamber just above the room in which the older chroniclers had carved their records. Here on paper, or some other material than clay, in a new language and new characters, a fresh set of scribes began and carried on a later history, and, as did the others before, piled their sheets in order one above the other. Then their work also came to an end, and after many years of neglect, the modern antiquary delves down and unearths the forgotten scriptorium. The contrast between the undisturbed piles of writing above and the confused and dislocated heaps below, the difference in the materials of the two and in the languages in which the records were expressed, told an unmistakable story of an older period during which a chronicle had been carried on without a break for a long time, of events by which the work was stopped and the chronicles rudely handled, of a long interval during which no history was written, and after this the beginning and carrying on of a new record.

Just in the same way, during ages still more remote, layer after layer of sediment was laid down on the seabed, with little or no break, till the pile grew to be hundreds or thousands of feet thick. On every layer nature imprinted characters, which we are now beginning to be able to read, and which tell us what were the

inhabitants of the water and what their surroundings when that layer was in process of formation.

Then came a time when earth-movements crumpled up and dislocated the layers which up to then had been lying spread out in such an even and orderly fashion, and when denudation swept away large parts of them. During all this time no deposit went on at the spot; in other words, there was an interval during which the geological history was interrupted. Later on the district was again lowered beneath the water, and in this water a second set of sedimentary layers was laid



FIG. 33. UNCONFORMITY.

down in level sheets on the top of the crumpled and scattered remnants of the older layers. In these the history begins afresh, and the characters imprinted on the newer beds tell of life and surroundings different altogether from those of the older set of layers. In such a case the later group

of rocks is said to rest *unconformably* on the older group, or there is an UNCONFORMITY between them.

Fig. 33 shows two rock-groups separated by an unconformity. In this section the beds of the upper group lie flat, while those of the lower group are steeply tilted and sharply truncated, and the truncation shows that they must have been largely denuded before the upper group was laid down. Now denudation takes time, and requires different conditions; there was therefore an interval of change between the deposition of the two groups.

LESSON XVI

OF SOME WAYS IN WHICH ROCKS HAVE BEEN ALTERED IN STRUCTURE SINCE THEY WERE FORMED

MEN, buildings, the face of the earth, all change as time moves on. What does not? Rocks are certainly no exception to this rule. Sometimes we can trace the change in operation, and sometimes we only know the end result, but even in this case we have the strongest reasons for suspecting that the rock is now far different from what it was when first formed. There are several means by which rocks may be altered. In our first lesson we found out that sandstone is made of sand and mud. But they are not sand and mud now; something has hardened them, and we had to pound the sandstone up to separate them. When we want to bind sand or stone together into a solid mass, we mix it with cement and pour water over the mixture, or we simply pour over it some cementing solution. It is the same in nature; water with something in it has in many cases bound the loose particles of sand into a solid rock. While the sand, &c., is loose, and until the crevices between the grains are completely filled up, water with matter dissolved in it easily finds its way through the mass. This matter may be picked up by the water as it passes through, or it may be brought in from outside. For some

reason or other the water after a time deposits the dissolved stuff between the grains, that is, in the fine crevices of the rock, and this acts as a cement and binds the loose particles together. We have seen this on a large scale in the case of the vesicular lavas. After the lapse of some time we find the vesicles filled up with crystalline matter, and the once vesicular rock has become an amygdaloidal one. In the case of the sedimentary rocks, the commonest cementing materials are calcium carbonate, silica, and sundry compounds of iron, and they produce what are known respectively as calcareous, siliceous, and ferruginous varieties of rock.

Another important agent of change is heat. We know how common clay when heated turns to brick, potter's clay to earthenware, and china-clay to porcelain. In like manner the slabs of sandstone used as the bases of iron furnaces are found after some time to have been greatly hardened and altered. The same results are brought about in nature when rocks are heated. If we look at the ground over which a lava-flow has passed, we find it reddened if it is clay, and in any case hardened and altered, and that this is due to the heat of the lava is easily proved. Where we have a contemporaneous sheet, only the underside is altered, for it alone was there when the lava was hot. But when we examine a dyke or sill, we find that both sides have been equally affected, for both were there when the molten mass was intruded. So, too, in the case of granite and other plutonic rocks. These we have shown to have been once molten, and as they are large masses, they must have contained much heat. Accordingly we find that in the rocks that surround them much greater change has usually been effected than in the case of lavas. Changes produced in this way are spoken of as *contact metamorphism*.

Metamorphism simply means change; but the term is only used when the change is considerable, and in this case the rocks which have undergone the change are called *metamorphic rocks*.

Heat may also be obtained from the interior of the earth, for it is known that the deeper down we go, the hotter it becomes. So it is possible that this internal heat may have altered rocks when they lay low down beneath the surface of the earth.

But no doubt the most important agent in altering rocks is the powerful squeezing which has bent the rocks about as described in the last lesson.

Not far from the Pass of Llanberis, where the rocks have been bent into folds, are the well-known Penrhyn slate-quarries. The slate is here so massive that a distant view scarcely shows any bedding in it at all. But on a closer view we notice here and there lighter-coloured bands, yellowish or greenish, running across the face of the rock. Pick up a lump of the slate crossed by one of these bands. The bulk is of dull grey tint and fine-grained texture, and as we saw in our first lesson, is mainly made up of material of the same nature as ordinary clay. The lighter-coloured band, however, is more sandy and coarser. These bands, then, are of a different kind of sediment, and the two together are the counterpart of shales with sandy layers which we have satisfied ourselves were formed under water. They are somewhat harder than these usually are, but scarcely differ from them in any other respect. Here, then, stands the problem before us. How have they been hardened? There are several things in the quarry itself that help us to an answer.

First, these light-coloured coarser bands do not run in straight lines across the face of the quarry, but like

the larger beds in the Pass above, they sweep up and down in a series of winding curves, and in some of these we may find that the edges are not smooth, but marked with small puckerings. These, as we have seen, are indications that the beds have been squeezed, and in the squeezing the particles of mud and sand have been packed closer together, and in this way the rock has been hardened. This can be imitated artificially, for, as we know, paper, coal-dust, and even clay can be rendered hard and firm by powerful pressure in an hydraulic press.

But there is something else in this slate which shows that the pressure here has been much greater than the ordinary pressure that the weight of the once overlying rocks might produce. An ordinary sample of hardened shale splits most readily along the planes of bedding. But nothing can induce a block from the slate-quarry to split along the light-coloured bands, though it is perfectly certain that they are beds.

For all that, the rock does split readily enough in another direction. A workman places a broad, sharp chisel on the top of a block and gives it a blow with a hammer. A slab comes off, bounded by two smooth flat surfaces. This slab he splits again and again in the same way, till the whole is broken up into plates thin enough to be used as roofing slates. You cannot see any cracks in the block, but the workman's treatment shows that the whole block is traversed by smooth flat surfaces all parallel to each other, along any of which the slate will split more easily than in any other direction. They cut across the bedding, but are parallel to a line which runs up the middle of each fold, and is called its axis. This way of splitting is called SLATY CLEAVAGE. This must be clearly distinguished from the cleavage of

crystals, for though the result is somewhat the same, the material in which it occurs and its origin are quite different.

From these observations we see that something has been done to the rock which has welded its different parts together, and at the same time has produced these fresh, numerous parallel planes of splitting.



FIG. 34. SECTION OF
A CLEAVED SLATE.

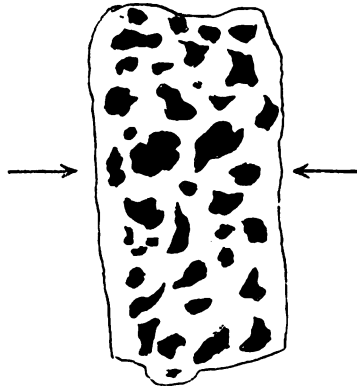


FIG. 35. SECTION OF AN
UNCLEAVED CLAY-ROCK.

If we examine under the microscope a thin section of a cleaved rock, we get a hint as to what has been done to it. The fine particles of mud of which the slate is made up have the shape and arrangement shown in Fig. 34. They are long, narrow, platy in shape, and all lying with their longer sides parallel to each

other. Now, a section of an uncleaved clay-rock shows under the microscope particles somewhat like those in Fig. 35. They are of all sizes and shapes, and they lie in all ways.

But suppose we put such a rock as this under a very powerful press and squeeze it in the direction of the arrows; would not the particles be flattened and turned round so that their flat faces all lie perpendicular to the direction of the pressure? That is, should we not get a rock with a structure like that in Fig. 34? And it would certainly be easier to split a rock with such a structure in the direction of the dotted lines than in any other direction. For along the dotted lines we should not have to break across a single particle, while in any other direction we must break across many.

This makes it look very much as if slaty cleavage had been caused by very strong squeezing of the rock in a direction perpendicular to the planes along which a cleaved rock most readily splits. And experiment shows that, in softer substances than slate material, cleavage can actually be produced in this way. It has often been done in the case of wax. Squeezing, then, much more powerful than any which we can command, would do all the three things we want to account for in slate. It would harden the deposit, bend it into curves, and make it cleavable. And that such squeezing has been here in action, is shown by the fact that the direction in which we require it to act is just the same as that in which we know that compressing forces have acted to produce the folds in the neighbouring rocks of the Llanberis Pass. The folds in these are much broader than those in the slate-quarries, but on a close examination we shall find puckerings at the edges of the beds like those in the slate.


It appears, then, that the same pressure will fold large masses of rock into arches and troughs, and convert a mass of clay into a cleaved slate. It may also have another result, which is more easily noticed. If the rock has fine bands in it, they may be crumpled up and folded in the most extraordinary way, as shown on the right-hand side of Fig. 26. The rocks are then said to be *contorted*. If we bend a piece of thread so as to follow the contortions of any conspicuous layer, and then pull the thread out straight, we can easily realize the amount of squeezing that the rock has undergone.

All the changes we have hitherto noticed have been explained by a single agency, either water, or heat, or pressure, but the most remarkable results are brought about when the agencies combine to do the work. It has, indeed, been shown experimentally that pressure and heat help water and other liquids to do many things which they are utterly unable to do without such aid. For instance, water may stand in a glass bottle for years without dissolving or corroding the glass, except to an extent so small as to be scarcely worth mentioning. But seal up some water in a glass tube, put the tube into a strong iron cylinder, and keep the whole at a moderately high temperature for some time, and the result is vastly different. In this case the water is aided by heat, and also by the pressure of the steam pent up in the cylinder. On opening the cylinder and taking out the sealed glass tube, we find the glass eaten away as a lump of salt would be in cold water, and the dissolved glass is chemically decomposed. Glass is a silicate; its silica is set free and crystallizes as quartz on the wall of the tube. If silicates of potash or soda are dissolved in the water, feldspars are formed as well as quartz. By similar methods other silicates and crystallized minerals,

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agreeing exactly with those found in nature, have been formed.

These and many similar experiments show that if we have a rock through which water is soaking, under great pressure and at a high temperature, changes of the greatest moment may be wrought in it, which would be altogether impossible under moderate pressure and at a low temperature. The minerals of which the rock is composed may be broken up into their chemical elements, and these elements may combine afresh and crystallize into new minerals. In this way an ordinary sedimentary rock, such as a sandstone, might come to look like a holocrystalline one.

We will now describe two of the most simple instances of metamorphic rocks.

Quartzite. This is easily seen with a pocket-lens, or better in a microscopic slice, to be very largely made up of grains of quartz. It was therefore, at first, a sandstone, but it is now far harder than the sandstone we dealt with in our first lesson. This difference is easily accounted for. In sandstones the grains are loosely bound together; the spaces between them are empty, or partly filled with some soft stuff such as clay. In quartzite these spaces are completely filled up with crystalline matter, most usually with quartz, which cements the grains together. One result of this is obvious to the eye when we look at the broken surface of a sandstone and a quartzite. In the sandstone the grains are held together only loosely, and the fracture in consequence runs round the grains and lays bare their dirty outsides, so the broken surface is dull. In a quartzite the grains are so firmly held together by crystalline matter as hard as they are, that the fracture breaks across grains and cement alike, and the broken surface glistens.

In most cases the cement has been deposited from water, holding silica and other substances in solution, as it has soaked through the sandstone. This may happen without the aid of pressure or heat, but the result is not so distinct from an ordinary sandstone as some quartzites are. Quartzites found among rocks that have been strongly folded, and where in consequence we know that they have been greatly pressed, are very hard and compact, for the pressure has aided the water to dissolve and redeposit the silica.

Also where sandstones have been subject to contact metamorphism, owing to their adjoining some volcanic or plutonic rock, they are baked into a kind of quartzite, in the same way as the sandstones which have been used for furnace hearths. In this last case certainly, and perhaps in some of the natural instances, heat has wrought the change without the aid of water.

Compounds of iron, potash, and soda may be present amongst the materials that fill up the spaces between the grains of the sandstone, and these, together with some of the silica of the quartz grains, may have been fused together, and the melted substance may have hardened into a glass, which binds the particles of the rock together.

But the method which has been the most efficient in the transformation of sandstone into quartzite has been the deposition of silica from solution in percolating water.

Statuary or Crystalline Marble. This is a limestone, and the microscope tells us that it is very largely, often wholly, made up of grains of calcite locking into one another. The grains are clearly distinguishable, particularly when seen in a thin slice under the microscope. They have not the external boundaries of crystals, but

show under crossed nicols a delicate mottled colouring, which proves them to be crystalline. Parallel bands of faint colour run across them, which are due to a peculiar structure in the crystal, like that seen in the case of the striped felspars. In such a marble no original grains are seen, and we cannot call one part more than another cementing material. All is equally crystalline.

But neither can we find grains in an ordinary limestone—its texture is too fine; so that all that has to be done to a pure limestone to turn it into a crystalline marble is to induce the substance to crystallize.

Now, many years ago, Sir James Hall was able to produce marble by shutting up limestone and subjecting it for a long time to heat. Here the pressure of the enclosed air, prevented from expanding, and the heat of the furnace did the work. In like manner limestones in the neighbourhood of volcanic and plutonic rocks have been rendered crystalline for short distances by contact metamorphism.

But the great masses of marble which are best known are not associated with any igneous rocks, but occur in mountainous regions, where we know that great pressure has been exercised, and this, with the aid of water, has effected the change. Calcium carbonate is soluble in carbonated water under weak pressures—under great pressures it would dissolve far more easily,—and in this way we may explain how bit by bit the whole of a limestone might dissolve and be reprecipitated in a crystalline form so as to produce a thoroughly crystalline marble.

These two instances of metamorphic rocks may be regarded as rather exceptional, inasmuch as they start with material that is almost entirely of one kind. In each case this material is of a kind that is easily crystallized, and is very common in that form. We

cannot say the same of clays and muds. They are usually complex in composition, and even if they were entirely formed of their principle constituent, it is not one that readily crystallizes, seeing that the crystalline mineral which is composed of this substance is a rare one. When, therefore, rocks composed of these materials become crystalline, it is by minerals of more than one sort being produced.

In this case a very remarkable feature is produced. The rock becomes flaky, and has a tendency to split into leaf-like plates. This is called *foliation*, and the rocks which show it are called *crystalline schists*. One of the most difficult problems in Geology is to account for the origin of these schists. In some cases it is pretty easy. When a rock has been originally deposited in thin layers, i.e. when it is composed of laminae of different compositions, then the processes we have already invoked for the production of quartzite and marble are enough to account for the schists, for each layer has crystallized according to its kind, and as were the laminae once, so are the folia now. Again, we have seen how pressure sets up slaty cleavage in rocks. This means that the materials are arranged in parallel surfaces. Any liquid which soaks through the rocks will find these directions the easiest along which to travel. Hence the chemical changes will go on most rapidly along these surfaces, and the new minerals which they give rise to will tend to be arranged in parallel belts.

In both these cases we know, or think we know, what was the direction of the original bedding. But in many cases we do not know this, and indeed we do not know whether there was any original bedding at all. Such is the case with the commonest kind of these schists, which is known as *Gneiss*.

GNEISS (Fig. 36), like granite, is a holocrystalline rock, and like granite it is made up of quartz, feldspars, and micas. In granite these minerals are put together without anything that can be called arrangement. But in gneiss they are more or less in parallel layers; sometimes a layer will be almost entirely made up of a single mineral, say mica; in other layers there will be much more feldspar,

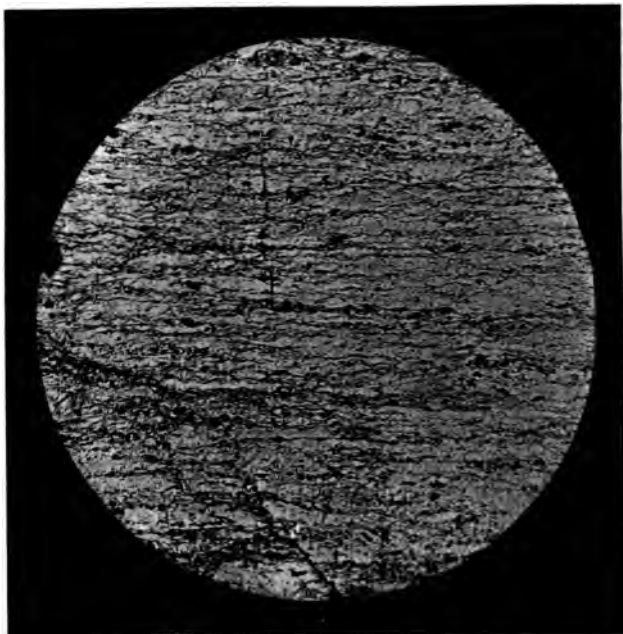


FIG. 36. FINE-GRAINED GNEISS.

and in others much more quartz than any other mineral. The layers do not keep the same thickness, but are in shape like wedges dovetailing into one another. They are also not flat, but always more or less undulating; often they are bent into large folds, and even little hand-specimens show them to have been crumpled up

into minute and complicated contortions and puckerings. Rocks of this type, with others composed of different materials, such as hornblende, and varying in the amount of their crumpling from layers or folia which are quite flat to others with inextricable contortions, occupy hundreds and thousands of square miles in the Highlands of Scotland, Norway and Sweden, Canada, and elsewhere.

Many of these rocks may be altered sediments, but they are almost all believed to be different now to what they were when they were first formed, so they are classed together as metamorphic rocks.

But though such rocks may be found occasionally in the neighbourhood of, and adjoining to, great masses of plutonic rock, this wide distribution shows that their metamorphism cannot be due to some local accident, such as the neighbourhood of a mass of granite, but must have been produced by a cause that acted over enormous areas. This kind of metamorphism, whatever it may be due to, is distinguished as *Regional Metamorphism*.

When we come to ask what has been the cause of this, we are not yet quite prepared with an answer. Some have thought that beneath the whole region there lies a mass of hidden granite, which only comes to the surface here and there; but this explanation will not apply when we can see many hundreds of feet of these crystalline schists in a single section. Others have seen in the folia of the schists the original lines of flow of an igneous rock; but this will not apply when the materials are not such as are produced by igneous agencies.

The most probable cause in the majority of cases is the powerful mechanical squeezing that the rocks have undergone. This is shown by the crumpling of their folia, and by the abundance of thrust-planes where they occur. Rocks which are thought to have been altered

by the agency of pressure and what follows from it are said to have undergone *Dynamic Metamorphism*. Proofs that crystalline schists are capable of being produced by this agency may be obtained by considering first what must be its result, and secondly what we actually see of the stages of the work.

Consider the thrust-planes already described. Where these occur, enormous masses of rock have been torn from their original home and forced over the surfaces of slightly-sloping rents. These masses as they were drawn along rolled out the rocks over which they moved, and were themselves rolled out in turn. If we look at a thin slice of a rock which has been obtained from a thrust-plane, we see that all has been broken up into long tongue-like pieces, which are composed of a mosaic of small crystals, formed where now we find them. This shows that the processes which must have taken place are such as would produce crystalline schists. Not infrequently there are several thrust-planes lying one over the other, and then the belts of rock lying between any two must have been, as it were, gripped and flattened out as between the jaws of a monstrous rolling-mill. Such action would tend to pull out the rock into sheets, and cause each sheet to move a little further than the sheet below it. This is often called *shearing*, but true shearing hardly goes as far as splitting the substance up into layers visible to the eye. In this way a platy structure would be set up, and this would enable the new-formed minerals to arrange themselves in nearly parallel surfaces. Where, however, the particles of the rock are very unequal in size and hardness, and yield unequally, the surfaces of division would become wavy and run into each other, breaking up the rock into masses thinning away to a sharp edge at both ends.

In any case the folia of the schists, before they have been contorted, have a certain direction, and something must have caused them to be arranged in this, rather than in any other direction, and this can only have been some mechanical agent, either pressure perpendicular to the folia, as in the case of the cleavage of slates, or an unequal force such as a shearing stress in their direction.

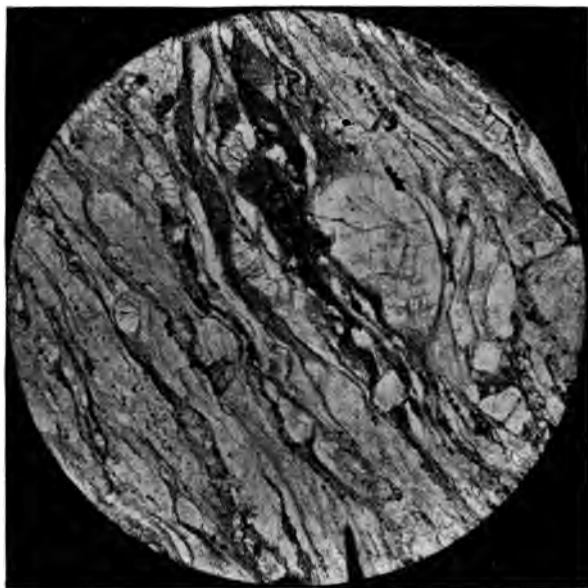


FIG. 37. FIRST STAGE OF CONVERSION INTO A GNEISS, SHOWING 'EYES.'

In some cases we are able to see the production of a gneiss in progress. For specimens may be collected which show every stage of the process which turned a granite, a lava, a sandstone, or a conglomerate into a crystalline schist.

In the first stage the rock is somewhat crushed, its large crystals or pebbles broken, and the fragments recemented (see Fig. 37). In a further stage the larger

crystals or pebbles are flattened and rolled out and the finer part of the rock more thoroughly ground down, while a sort of mangling process has gone on by which these finer portions have been dragged out into wavy bands which sweep in flowing curves round the larger lumps (see Fig. 38). These larger uncrushed lumps in



FIG. 38. FURTHER STAGE OF CONVERSION INTO A GNEISS.

such a rock are spoken of as *eyes*. Further rolling out crushes down even the 'eyes,' till they become merged in the general platy matrix. Even hard quartz pebbles are rolled out to thin plates like pennies. So at last, along certain belts where the crushing has been most intense, every grain or crystal becomes ground down, and the original structure of the rock is so utterly destroyed that it is impossible to say what was

its character in the unaltered state. It may then appear like Fig. 36. The chemical changes, which, as we have pointed out, accompany and are aided by these mechanical operations, also produce a variety of crystalline minerals, which group themselves in parallel lenticular bands.

Such was certainly the way in which many crystalline schists were formed out of sundry kinds of pre-existing rocks, but to how many of the schists this explanation will apply we cannot at present say.

One question may very reasonably be asked, by any one who has read the foregoing, namely, what caused the enormous pressures which we have employed so freely in our explanations? This, however, does not admit of a simple answer. Many have been given, none quite satisfactory, but they depend on matters which cannot be discussed in the *first* lessons in Geology. They must be reserved by the student till a later stage in his progress.

LESSON XVII

HOW THE SURFACE OF A COUNTRY IS AFFECTED BY ITS GEOLOGY

IN the course of our study we have oftentimes referred to denudation; sometimes to account for the source of the materials of which some of the rocks are composed; and sometimes to account for our seeing the structure of the ground which, according to our explanation of it, ought to be deeply covered with other material.

Now, as the present surface of the country is the limit of what has *not* been removed by denudation, it is plain that this agent is primarily responsible for the forms which the surface takes. And that this is so we have ample independent evidence.

When we see in an old building a window such as is shown by the dark part of Fig. 39, we say at once, 'That window was not built so; time and weather have worked their will upon it, and parts of it have mouldered and crumbled away.' But from what is left, it is easy to see what the window was when perfect, and we have no hesitation in putting back the missing bits, as is done by the dotted lines. Just so, when we make a geological section across a valley and find it such as is shown in Fig. 40, we see at a glance that there was not

always a valley there. The bed of rock that caps the hill on the left, and is numbered 3, is exactly like the bed at the top of the hill on the right; the same in composition and grain, and both yielding the same fossils. It is a rock that was formed under water, and it could not have been laid down in the separate patches, which

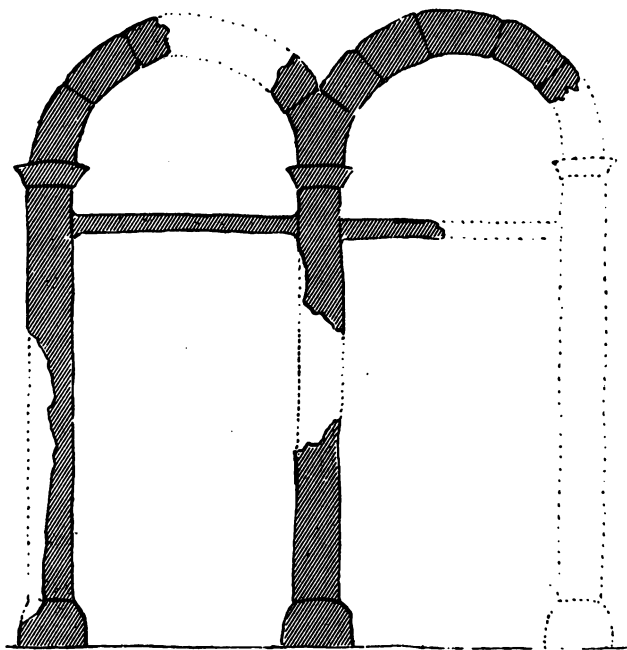


FIG. 39. WORN WINDOW.

are all we now see of it. There must have been once a broad sheet of it stretching across from one hill to the other, as shown by the dotted lines. All that has been said of bed 3, is equally true of the underlying bed 2. We may look upon the intervening valley as nothing but a great ditch dug out across the country. In this

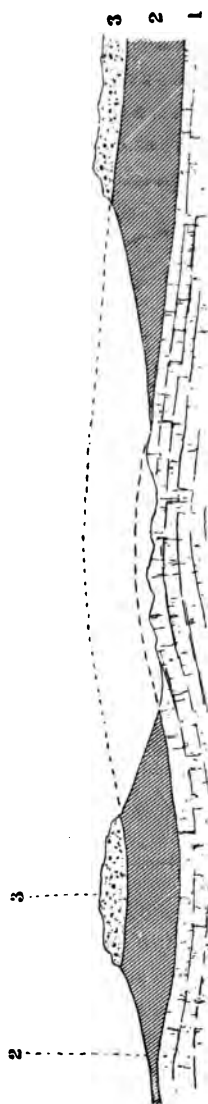


FIG. 40. DENUED VALLEY.

case the hills and intervening valley owe their existing contours to the action of denudation, and denudation alone. There is nothing else that distinguishes one part from another but this, that while the hills may have been denuded, the valleys have been much more denuded.

The section in Fig. 40 is not at all an uncommon one—so common, indeed, that when the part of the bed 3 on the left is isolated on all sides from the main mass, it has a special name, *outlier*, given to it, and in all cases these outliers are due to denudation alone. A large number of hills are nothing but great outliers, though their top bed may be the last relic of the deposit, when the rest has been swept away.

But there are other causes which produce the differences of height in the surface of the ground. When the beds are folded into arches and troughs, the arch stands necessarily in the first place at a higher level than the trough, and will form a hill while the trough is a valley. But whether or not they remain so, depends on the power

of the denuding agencies, and it often happens that the relation is reversed. What was at first a hill is denuded so rapidly that it becomes a valley, while the intervening valley is denuded so slowly that it is left as a hill, as is indicated in Fig. 40. If, however, the folds are sharp and numerous, and denudation cannot act quickly enough, we get a mountainous region; and it is known that though very strong folds may occasionally be found on pretty flat ground, they are best sought for among the mountains (see Fig. 26). The deposition of later material on the surface of the valleys, however, often covers up these irregularities and makes them nearly flat.

The surface of the country, then, is the result of the interplay of three distinct agencies—*denudation*, *elevation*, and *deposition*.

Of these three, elevation by folding affects a large area at once. It includes all kinds of rocks, and is not affected to any great extent by their character. Sandstone hard or soft, clays and limestones, all rise together into the arches and sink into the troughs—there is no difference. The later deposition is usually of loose sand, mud, or stones, and the surface produced by it is mostly horizontal; but denudation varies immensely with the nature of the rocks; broken rocks, soft or loose rocks, are easily carried away, while compact and hard rocks resist its action. Moreover, each kind of rock has its own peculiar way of weathering, and a practised geologist can often tell what a hill must be made of before he reaches it.

A very good illustration of all this may be obtained in a railway journey from Chester to Dolgelly. We here cross a country which shows almost every imaginable variety of feature, from the flattest of plains to the

wildest and most rugged of hills. Nor is it difficult to make out as we go along that every change in the scenery corresponds to some change in the general nature of the rocks.

On leaving Chester we see spread before us a broad tract that looks as flat as a table, and is almost as flat as it looks. This flatness is due to two causes. In the cuttings we see a soft sandstone very uniform in character and lying nearly flat, and this extends over the whole plain before us. Being flat, it gives rise to no hills of itself; being uniform in composition, there is not more denudation in one part than another, even if it were not so low-lying that little denudation can take place anywhere. But besides this the flatness of the ground has been made more complete by the river Dee. In the higher part of its course among the Welsh hills, this stream has a steep fall and a rapid flow, and has carried down much sand and mud. When it emerges on to the flatter country, it floods it now and again, and spreads its burden of sediment over the ground, filling up and levelling any little hollows that may be on it.

To the west of this plain we may see rising before us a long line of hills. They do not spring up abruptly, but seem to rise gently out of the flat with a moderate slope, and end off along an interrupted ridge which forms the sky-line. We have to travel some distance before we can find out what these hills are made of, but some little way beyond Wrexham we see in a deep cutting some hard thick-bedded sandstones, shales, and coals dipping to the north-east at an angle of about 20° . We now see why this country rises up from above the Cheshire plain. There the rocks are flat, here they dip towards the plain, and must come up from underneath the rocks of the plain, which are below them in level.

It is a case of elevation. But denudation has been at work as well, for the hills themselves have not so great a slope as the rocks of which they are made. If these rocks had been left alone after they were elevated, the hills would have been much higher. As it is, they have been worn down, while the plain has not been altered to any extent. Hence they are hills in spite of denudation.

When we get up to the ridge of hills which we saw in the distance forming the sky-line, we find them decidedly more rocky, and composed of hard limestone. They rise, however, from below the sandstones and shales of the former hills, and we must suppose that when first the elevation took place, the sandstones and shales overtopped the limestones. Then denudation began. The sandstones, &c., were worn off the tops of the limestone hills, but when these were reached, the denuding forces had a harder substance to work on. Consequently, while the softer beds continued to be carried away, the limestone was left outstanding. Here, then, the hills are due to denudation acting less on a hard rock than on a soft one.

Moreover, these limestone hills have a stamp of their own, quite different from anything we have yet seen on our journey. The hillsides rise in a long succession of steps and terraces, so regular that they remind us of the great flights of steps which lead up to a Greek temple. Each step is the face, and each terrace the surface of a bed, and as the eye follows their windings round the hill and along the valley side, we see clearly that the rock is dipping to the north-east, and must dip under the group of sandstones and shales, as stated above.

As we travel on we find this terracing confined more and more to the upper parts of the hills, and about Llangollen we see a different kind of rock, and a more

uniform slope of the hill-side. What this rock is we can see in many places in the bed of the Dee. It is mainly hard, dark-coloured, slaty stuff; the beds too have not the steady dip of the limestones—sometimes they stand up at high angles, sometimes they are nearly flat, sometimes they are sharply bent. They lie, in fact, in a succession of folds, and the limestone rests unconformably on their edges.

From Llangollen to Bala Lake we have all along very much the same type of surface as in the low ground below the limestone. It rises into hills, and the valleys are narrow and steeply cut, but they are neither rugged nor craggy, but have a general roundness of outline. The rocks are tolerably uniform in character, and so weather into smooth and rounded forms, which are mantled with a covering of turf. This is characteristic of slate hills.

But on either side of Bala Lake we see before us a very different type of scenery. In place of smooth grassy slopes, the hill-sides bristle with crags of bare rock and long lines of precipices steep as a wall. The hills no longer have rounded tops, but culminate in sharp edges and towering peaks, and we feel that though they are small for mountains, they are truly mountainous in aspect. On the one side are the Arenigs, on the other side the Arans, and along the valley of the Mawdach, through which the railway runs, there lies before us a long vista of craggy peaks.

All the distinctive characters of this striking landscape are entirely due to denudation acting on rocks of different character. These crags are largely composed of lavas and volcanic ashes. The whole of them have undergone enormous squeezing, so that beds, such as the lavas, which were hard enough to begin with, have

been further hardened, and beds originally loose like the ashes have been compressed into very solid and durable stone. The whole type of rugged scenery is characteristic of rocks of volcanic origin.

In this journey we have illustrations of the principal features of a variety of types of scenery, and are able to trace their connexion with the character of the rocks, and with the particular agency which had most to do with their construction. It will be an interesting exercise to apply the lesson here learnt to other parts of the country. It requires, as will be seen, the power to recognize the character of the rocks and their position in the ground.

We will take, however, another example of a more simple character drawn from the traverse we have already made from Oxford to Brighton. Near Reading the sands and gravels are nearly horizontal, and the surface of the ground owes its character to the deposition of these. Then, as we have seen, comes a great arch, which used to extend when first it was formed from Guildford to Brighton, but the greater part of which has now been denuded away (see Fig. 25). But even what is left forms hills and valleys, and it is for these we have now to account.

As the chalk once extended over the arch, it is plain that it must have first been denuded away before the underlying clay and sand could be attacked. As soon, however, as this was done, it was a contest of endurance between the hard chalk and the softer, looser clays. The chalk has won, and stands up on both sides—the North and the South Downs, with a steep slope to the clay, due to the difference of denudation, and a more gentle one on the other side due to the elevation of the arch. The steep slope thus formed is called an *Escarpment*. So

the presence of the North and South Downs is entirely due to the chalk being better able to resist denudation. If the top bed of the arch had been soft, it would not have formed hills at the present day.

In fact, within the Wealden District, according to our drawing, soft rocks once extended over the surface from the north to the south side; but they are all now absent from the middle, and the harder sandstones which lay beneath them now stand up as hills in the centre, while the soft rocks both above and below them occupy the valleys. It is perfectly illustrative of the dependence of hill and valley on the character of the rocks, and mostly in this case on their hardness or softness.

But in this district there are valleys of peculiar character which require a special explanation. The great chalk ranges of which we have spoken are not absolutely unbroken. Every here and there great river-valleys cut across them, making, as it were, breaches in their wall-like structure. Such a valley is that of the Mole near Dorking, or the Wey at Guildford. These are spoken of as *Transverse Valleys*.

Now, there is no difference whatever between the chalk on the sides of these valleys and that which forms their base, so it cannot be anything in the character of the rocks that has determined their course. Still more remarkable is it that the water actually runs off what is in general a low country, right through a range of hills,—of course in a gorge. But block up that gorge, and no river could possibly make it again, as things are now—that is pretty plain; nor could it ever have done it in times past, if things were then as they are now. There is no other conclusion to come to, but that the rivers must have made the gorges when things were different to what they are now. In the present case we have quite in-

dependent reasons for believing that at one time things were very different, for instead of valleys lying between two ranges of chalk hills, there was formerly a great arch extending from one range to the other. Restore this, and the history of the rivers becomes quite clear. Off such an arch, so long as the middle remained highest, the water would run down the sides, and cause a groove in them, as rivers will. Once in the groove, the river could never get out of it again, but when the denudation of the surface lowered the general level of the country inside the chalk ranges, the rivers kept pace with it, and always cut the grooves a little deeper. The rest of the hill it could not touch.

This is the general explanation of all these transverse valleys, and of others that have remarkable courses out of valleys into hilly regions and out again. When they commenced to run, what are now valleys were hills, and what are now hills were valleys. It is an admirable illustration of the enormous changes which in course of time denudation can bring about on the surface of the country.

LESSON XVIII

ABOUT FOSSILS. HOW THEY ARE PRESERVED, AND WHAT THEY TEACH US

WE have already spoken in Lesson IV about fossils enclosed in rocks, but it is not so easy to give an exact and comprehensive definition of a fossil. Perhaps the best is this: *a fossil is a relic of some organism buried in the earth during geological time.* This gets over the difficulty of deciding how old a shell or bone must be before it is called a fossil.

There are many ways in which a fossil may be imbedded in a rock. The commonest is when animals are living on the sea-bottom, or when those that live in the open water above drop their shells, when they die, to the bottom, at the same time that mud or sand from the edge or the surface of the land is being deposited there. The dead shells or bones are covered up by the mud and buried out of sight, never to come to view again till the rocks formed by this mud are again denuded, and their inner parts laid bare. At first nothing happens to the shell; as it was buried, so it remains, just as it would do if it had lain in a cabinet. Shells are not easily destroyed, neither are teeth, nor bones, nor other things which are usually found fossil. Many fossils, therefore, are in no way different from the dead shells of the present day; and in places where the deposits are not

very old, as in Suffolk, it is difficult to distinguish the periwinkles that have been buried ages ago, and the shells that have been thrown up by the neighbouring sea.

We must not think, then, that a fossil is necessarily a petrification. This latter name is given to things that have either become stony internally, or have been coated with a stony deposit. Fossils *may* be petrifications in the first sense, but this makes no difference to the geologist—they are fossils, whether petrified or not.

But after a time changes take place in the buried fossil as in the rock around it. We have seen how much is done by percolating water, and that this water often carries calcium carbonate in solution. If the fossils are calcareous, they form one source of this material, and so it is carried away from them and they decay. What is left is not very different from what we should find if we left a calcareous fossil in acid for some time—probably mere dust, the parts which are most easily dissolved having been removed, and the rest left behind. So we often find that fossils are crumbly—we cannot get them out whole—or they have disappeared altogether and only left holes behind.

But though the fossils themselves are gone, they may have left easily recognizable traces behind, if the enclosing rock be of fine material, fitted to take a mould of what is enclosed in it. In this case, as the shell or bone lay buried, the mud around was pressed against it, and a mould was taken of its surface, and mud often got inside and took a mould of the interior. If the fossil is afterwards dissolved away, and the rock has hardened, we shall get a hollow where the shell or bone has been; and if we fill this with some casting material, we get a perfect cast of the original as it was buried. In other cases the original shell was filled with mud that got

inside, and supported it on all sides, so after the shell has gone an interior cast lies loose inside the exterior mould.

In some instances the original relic was itself only an impression, as when we find marks of ancient footprints as shown in Fig. 41. As the animal walked over the mud he left a hollow mark where his foot had rested, and when the mud was dry another deposit came and

filled up the hollow and took a cast of the footprint, which is here represented.



FIG. 41. FOSSIL FOOTPRINTS.

It often happens, however, that as fast as the water takes away one particle of the buried fossil, something else takes its place, and in this way, particle by particle, a fossil which when first buried was made of calcium carbonate, ends by being made of silica or some other mineral. These

may be truly called petrifications. There are quite a number of minerals that may in this way replace the original ones, some of them being metallic ores. When this process has taken place, the interior structure of the fossil is often beautifully preserved, and we can study this structure as easily, or more easily than in a living example. This is especially the case when the stems of plants are buried. In these it sometimes happens that the woody tissue has been replaced particle

by particle by mineral matter, and we can see this tissue as well as we could have done on the day in which it was imbedded in the mud.

How long a fossil remains in its original state before these changes take place in it depends in part on the kind of rock it is imbedded in, and in part on the material it is made of. Fossils imbedded in sand soon go, and we must not rashly conclude that because we can find none now, that none have ever been there. If they are found at all, it is mostly as hollow casts. Fossils in clay last longer, because the water cannot so easily get to them, but fossils in limestone last longest, because the stuff they are buried in is the same as that they are made of, and it is easier to dissolve, because it has already been broken up into fine particles.

But the material the fossils are made of is perhaps more important. Some materials are more easily dissolved than others. In this case the more soluble ones will disappear, and the less soluble will remain, though both were buried at the same time. Other materials are partly soluble, and enough is left of the insoluble part to show the original form of the fossil before the soluble part was removed.

But whatever the rock, and whatever the material of the fossil, what is left after these changes is indestructible, till the rock itself is destroyed. There remains, in fact, only a marking on the rock to show what once was there. And this explains what would be otherwise most curious. If a soft animal is buried, and it has sufficient strength to impress its form on the surrounding mud, the impression it makes is never afterwards destroyed. So we get in old limestones impressions of jelly-fish, and in still older slates impressions of worms and their tracks.

But what does the study of fossils teach us?

In the first place they provide us with a time-scale for the rocks in which they lie. When we go to a section in a quarry where the rocks are lying pretty flat, and we are sure that no inversion (see p. 166) has taken place, we naturally conclude that the rocks which lie at the top were laid down later than those at the bottom. This gives us a time-scale for that particular quarry. If, then, we find the top rock of one quarry lying at the bottom of a second quarry, we also conclude that the rocks now lying above it there were formed later still, and so we enlarge our time-scale. But the doubt comes in, whether the rock in one quarry that we think is the same as a rock in a second quarry is really so. And this doubt becomes very strong when the quarries or openings are far away from each other, and when the rock itself is not quite the same. It was found out, however, long ago, by William Smith, after he had tested it over a great part of the country, that if the two rocks contain the same fossils, we may safely identify them as being made during the same period. With this principle to go upon, the fossils we find enable us to divide geological time into a number of periods, and so we learn the succession of animal and plant life on the earth, and even arrange the events that have happened to the rocks themselves in proper chronological order. Fossils, therefore, form the groundwork of all geological history.

Secondly, fossils tell us the conditions under which the various strata were laid down. Ferns, for example, do not live in the sea, nor do oysters in fresh-water lakes. If, then, we find a fossil fern in any rock, it is very unlikely that that rock was formed under the sea. It might possibly have been formed between tide-marks, and the

fern buried by the mud brought by the rising tide, but if once it got in the water it would float till broken up. But the great probability is that it was formed on the land in some marsh, where leaves constantly fall on the mud and are buried by the next flood. On the other hand, if we find an oyster in a rock, we know at once that the rock was not formed in a fresh-water lake, for oysters do not live in such places. There must at least have been *some* salt in the water, and the rock is probably marine. Other kinds of fossils are even more instructive than this, e. g. the Foraminifera and the corals, which are always marine.

There is a limit to this use of fossils, because some classes of animals might leave their relics just as well in one place as another. A land reptile, for instance, when dead, might leave his carcase anywhere, and his hard teeth would be carried just as a pebble would be carried, according to their weight. Also many of the older fossils are so unlike any living ones, that we do not know what were their conditions of life, and whether they were restricted or not to fresh or salt water.

But this is not the only distinction to be drawn. In the sea itself different animals live at different depths. If any fossil, then, belongs to a group now found only in abundance at the bottom of deep seas, we have a strong reason for believing that the containing rock was laid down in great depths. The arguments here, however, require great caution, as there are several things that may render them worthless in any particular case.

Thirdly, we have seen that in many places, what was once sea is now land ; and what was once land is now sea. So in the course of geological history there have been many seas, bounded by many shores. Fossils help us to trace these old shores. For out of the many animals that

were living at the same time there would be some which required special conditions and others that could live almost anywhere. These latter would leave their relics in all the deposits that were then being formed, and prove to us that these deposits, though very different in character, were all made at nearly the same time. The former would be found only in certain areas, and they would prove that these areas were subject to special conditions and were separated from the rest by some barriers. The most probable barrier in such a case would be a mass of land which prevented the water on one side communicating with that on the other, perhaps some isthmus like that of Panama. In this way the position of the old land may be clearly indicated to us by the fossils. One example of this must suffice. In the north of England we find certain deposits in Durham and Yorkshire; and on the other side of the Pennine Chain we find other deposits in Cumberland and Lancashire ('Permian'), which the contained fossils prove to have belonged to the same geological period. But the deposits themselves are very different in character, and could not have been deposited in the same sea. There must have been land between them, where now the Pennine Chain is found. We cannot go further into this question, which is scarcely elementary, but we can easily see that the study of fossils opens up a wide field in purely physical geology.

The fourth use to which fossils may be put is still more physical in its character. We can by their means sometimes determine how far rocks have been squeezed out of their original shape. When any fossil has peculiarities of its own by which we can recognize it in a mis-shapen condition, we are able to identify it with others that still retain their proper shape, and the

difference between the two shows how much the rock has been pulled out since it was formed. Thus in Fig. 42 *a* we see a fossil compressed from side to side, so that it looks very long and narrow. In Fig. 42 *b* we see the same fossil which has been compressed from top to bottom, so that it looks very short and broad.

The figures represent a *trilobite*, which is well known to have a symmetrical form, and we can see that in the

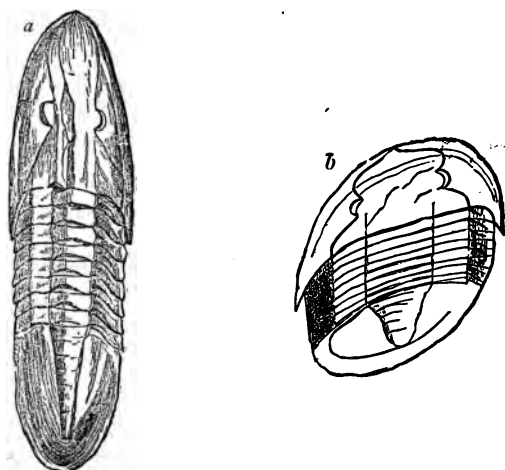


FIG. 42 *a* and *b*. THE SAME FOSSIL DISTORTED IN DIFFERENT DIRECTIONS.

smaller details these two figures everywhere agree, differing only in the relative proportions of the parts. We are convinced, therefore, that these fossils have been distorted since they were buried, just as the reflection of one's face in concave cylindrical mirrors is distorted. Here the distortion must have been brought about by earth-pressures acting in each case perpendicular to the direction in which the fossil has been lengthened.

We have already learnt how the rocks have been folded on a large scale, and squeezed into puckers on a smaller scale, and we always find that these fossils indicate the same directions of pressure as do the foldings and puckerings, and they also give the amount by which the rock has been squeezed in one direction and lengthened in the other; and in this way the physical history of the region is taught us by the fossils.

As fossils are usually very attractive to a beginner, and he is tempted to collect them, a practical caution on the method of collection may not be out of place. From what has just been stated it is obvious that the whole, or nearly the whole, scientific value of a fossil is in relation to the rock in which it is found. If the fossil be picked up loose, and we cannot tell where it comes from, we may just as well throw it away again for all the original scientific value it has. It may, of course, be a duplicate of some well-known fossil, and may obtain some borrowed value from that, but it can never teach anything we did not know before. Hence every student should be most particular to label accurately every fossil he finds, not only from the general locality, or the general formation that he finds it in, but from the particular quarry and from the particular bed in that quarry. In this way only can he hope to repay the instruction of his teachers by giving them welcome information about special localities which they cannot otherwise so easily obtain.

INDEX

- Acid and basic rocks, 123.
- Air-saddle defined, 162.
- Alteration of rocks, 173 *et seq.*
- Amorphous minerals, 119.
- Amygdaloidal structure, 132.
- Analysis, 20.
- Anthracite, 27.
- Anticlinal defined, 162.
- Artificial sections, 4.
- Ashes, 132.
- Atomic weight, 19.
- Augite, 123, Fig. 14.

- Basalt, 128.
- Bedding, 43.
 - irregular, 43.
 - regular, 43.
- Biotite, 122.
- Bituminous shale, 49.
- Bottom moraine, 112.
- Brown coal, 96.

- Calamites, 96.
- Calcareous tufa, 69.
- Calcite, 55, Fig. 5.
- Cannel coal, 102.
- Carbonaceous shale, 49.
- Carbonate of iron, 31.
- Caverns, 63.
- Cement-stones, 49.
- Changes of land and sea, 80.
 - in rocks, agents of, 174.
- Chemical compounds, 18, 19.
- Chemically-formed rocks, 61.
- Chert, 57.
- Chester to Dolgelly, origin of scenery along the line, 193.
- China-clay, 28.
- Cindery base of lava, 142.

- Clastic rocks, 36.
- Clay, 14, 24.
- Clay ironstone, 49.
- Clean coals, 97.
- Cleavage planes in crystals, 55.
- Cleaved and uncleaved rocks, 177, Figs. 34, 35.
- Club-moss, 93, Fig. 8.
- Coal, 91.
 - origin of, 96.
- Colouring matter, 29.
- Columnar structure, 134, Fig. 17.
- Conchoidal fracture, 57.
- Concretions, 49.
- Conglomerate, 48.
- Contact metamorphism, 174.
- Contemporaneous lavas and tuffs, 131, Fig. 16.
- Contortions in rocks, 179.
- Coral limestone, 65.
- Crust of the earth, 6.
- Cryptocrystalline rocks, 125.
- Crystalline cleavage, 26.
 - substances, property of, 12.
- Crystals, 22.
 - nature of, 114.

- Débris, 40.
- Denudation, 40.
 - effect on scenery of, 193.
- Denuded valleys, 192, Fig. 40.
- Denuding agents, 40.
- Deposit, effect on scenery of, 193.
- Depth of old seas, how determined, 204.
- Derivative rocks, 36.
- Devitrification, 129.
- Diatoms, work of, 65.

- Dichroic minerals, 122.
 Diorite, 151.
 Dip defined, 162, Fig. 27.
 Distortion of rocks, proved by fossils, 206, Fig. 42.
 Distribution of rock material, 72.
 Dolerite, 126, Fig. 13.
 Dolomite, 82.
 — how formed, 90.
 Double refraction of calcite, 56.
 Drift coals, 101.
 Dykes, 133, 144.
 Dynamic metamorphism, 186.

 Elements, 18.
 Elevation, effect on scenery of, 193.
 Equivalent, 27.
 Erratics, 113.
 Escarpment defined, 197.
 'Eyes' in Gneiss, 187, Fig. 37.

 Fault defined, 164.
 — hade of, 165.
 — reversed, 167.
 — throw of, 164.
 — trough, 165, Fig. 29.
 Felspar, 16, 121.
 Felspathic mud, 26.
 Ferric oxide, 30.
 — peroxide, 30.
 — sesquioxide, 30.
 Ferrous carbonate, 31.
 Flint, 57.
 Fluid cavities in quartz, 150, Fig. 21.
 Fold-faults, 166, Fig. 30.
 Folding of rocks, 155 *et seq.*
 Foliation, 183.
 Foraminifera, 64.
 Fossils, 35, 200.
 — distortion of, 206, Fig. 42.
 — how preserved, 200, Fig. 41.
 — how to collect, 208.
 — teachings of, 204.
 Fresh-water and marine deposits, how determined, 204.
 Frost, action of, 38.

 Geology defined, 1.
 Girvanella, 69.
 Glaciated surfaces, how recognized, 108, Fig. 11.

 Glaciers, origin of, 106.
 Glassy rocks, 126.
 Globigerina ooze, 64, Fig. 6.
 Gneiss, 183, Fig. 36.
 — 'eyes' in, 187, Fig. 37.
 — stages of change, 187, Figs. 37, 38.
 Granite, 146 *et seq.*, Fig. 20.
 Grits, 16, 48.
 Gypsum, 83.
 — how formed, 89.

 Haematite, 30.
 Hardening of rocks, 173.
 Heat, action of, in altering rocks, 174.
 Highlands, inversion and thrust-planes in, 169, Fig. 22.
 Hog's Back, 158.
 Holocrystalline rocks, 125.
 Hornblende, 123, 151, Fig. 22.
 Hydrated minerals, 28.
 — ferric oxide, 30.
 Hydrothermal fusion of granite, 151.

 Icebergs, 106.
 Ice-sheet, 106.
 Interbedded volcanic rocks, 144.
 Inversion, 166.
 — and thrust-planes, 169, Fig. 32.
 Iron pyrites, 50.

 Joints, 163, Fig. 28.

 Kaolin, 28.
 Keswick, contemporaneous lava-flows near, 131, 143, Fig. 16.

 Laminae, 44.
 Lateral moraines, 111.
 Lava, structure of, 141, Fig. 19.
 Lepidodendron and Lepidostrobus, 94, Fig. 9.
 Limestones, how formed, 18, 63.
 — tested, 51.
 Limonite, 31.
 Llanberis Pass, folding of rocks in, 155.
 Longitudinal section, construction of, 157, Fig. 24.

- Magnesian limestone, 83.
 Magnetite, 124.
 Marine and fresh-water deposits,
 how determined, 204.
 Master-joints, 163.
 Mechanical mixture, 18, 19.
 Mechanically-formed rocks, 61.
 Melting of rocks in the dry, wet,
 and hydrothermal ways, 150.
 Metamorphic rocks, 175.
 Metamorphism, contact, 174.
 — dynamic, 186.
 — regional, 185.
 Mica, 15, 48.
 — varieties, 122.
 Micaceous sandstone, 48.
 Minerals defined, 21.
 Molecules, 115.
 Moraine, 111.
 — profonde, 112.
 Mother-of-coal, 92.
 Mountain limestone, variations
 of, 78.
 Muscovite, 122.

 Natural sections, 4.
 Necks, 133.
 Névé, 105.

 Obsidian, 139.
 Old shore-lines, how traced, 79,
 205.
 Olivine, 123.
 Oolite, 68.
 Organically-formed rocks, 61.
 Orthoclase felspar, 25, 121, Fig. 2.
 Outlier defined, 192.

 Pea-stone, 68.
 Penny-stone, 49.
 Penrhyn slate-quarries, 175.
 Perlitic structure, 135, Fig. 18.
 Physical properties of minerals, 24.
 Pisolite, 68.
 Pitchstone, 129, Fig. 11.
 Plagioclase felspar, 122.
 Potash felspar, 25.
 Pressure, action of, in altering
 rocks, 179.
 Pudding-stone, 48.

 Qualitative analysis of rocks, 20.
 Quantitative analysis of rocks, 20.

 Quartz, 12, 120, Fig. 1.
 — composition of, 17.
 — fluid cavities in, 150, Fig. 21.
 — the last to crystallize in granite,
 151.
 Quartzite, 180.

 Radiolaria, 65.
 Rain, action of, 39.
 Reactions, 20.
 Regional metamorphism, 185.
 Relation of volcanic and plutonic
 rocks, 153, Fig. 23.
 Reversed fault, 167.
 Rhombohedra, 56.
 Ripple-marks, 88.
 Rivers, action of, 41.
 Roches moutonnées, 110, Fig. 12.
 Rock defined, 5, 22.
 Rock-salt, 81, Fig. 7.
 — how formed, 85.
 Roe-stone, 68.

 Saddle defined, 162.
 Sand, 48.
 Sand-rock, 48.
 Sandstone tested, 9.
 — how formed, 34.
 — varieties of, 48.
 Sandy shale, 49.
 Schists, crystalline, 183.
 Scoria, 140.
 Scree, 39, Fig. 3.
 Sea, action of, 41.
 Seat-stone, 97.
 Section from Oxford to Brighton,
 159, Fig. 25.
 Selenite, 83.
 Septaria, 50.
 Serpentine, 124.
 Shale, 49.
 Sharp and gentle folds passing
 into each other, 161, Fig. 26.
 Shearing of rocks, 186.
 Sigillaria, 75, Fig. 10.
 Silica, 17.
 Sills, 133, 144.
 Slaggy structure, 142.
 Slaty cleavage, 176 *et seq.*
 Snow-line, 104.
 South Downs, 160.
 Specific gravity, 23.
 Spherulitic structure, 136.

- Spore-coals, 95.
Stalactite and stalagmite, 70.
Statuary marble, 181.
Stigmaria, 75, Fig. 10.
Stratified rocks, 43, Fig. 4.
Strike defined, 162, Fig. 27.
Subsoil, 5.
Surface features, how produced, 190 *et seq.*
Suspension and solution, 59.
Syenite, 152.
Synclinal defined, 162.
Synthesis, 20.
- Terminal moraine, 111.
Thrust-plane, 167, 186, Fig. 31.
Till, 112.
Time-scale, how determined, 204.
Transverse valleys explained, 198.
Travelled stones, 113.
Travertin, 70.
- Trough defined, 162.
— faults, 165, Fig. 29.
Tuffs, 132.
- Unconformity, 170, Fig. 33.
Under-clay, 97.
- Vesicular top of lava, 141.
- Water, action in altering rocks of, 173.
Water-stuff in volcanoes, 139.
Weald, origin of scenery of, 197.
Wealden area, 158.
Weathering of rocks, 36.
- Volcanic ash, 140.
— bombs, 140.
— eruptions, causes of, 139.
— rocks, 137.
— tuff, 140.
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